DOCUMENT RESUME

ED 271 298 SE 046 652

AUTHOR	DeLuca, Diana Macintyre, Ed.
TITLE	Essays on Creativity and Science. Proceedings of the Creativity and Science Conference (Honolulu, Hawaii, March 23-24, 1985).
INSTITUTION	Hawaii Council of Teachers of English, Kaneohe.
PUB DATE	86
NOTE	310p.
AVAILABLE FROM	Hawaii Council of Teacher of English, Windward Community College, 45-720 Keaahala Rd., Kaneohe, HI 96744. (Price $8.00).
PUB TYPE	Collected Works - Conference Proceedings (021)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	Case Studies; *Creativity; Essays; Fine Arts; Humanistic Education; *Humanities; Imagination; *Interdisciplinary Approach; Philosophy; Psychology; Science Education; Science History; *Science Instruction; *Sciences; Values

ABSTRACT

Essays focusing on creativity in the humanities and sciences are contained in this proceedings of the Creativity and Science Conference. The presentors, who represented many academic disciplines, agreed that creativity is as essential to the scientist as to the humanist and that one can prepare for it but not instruct or be instructed in achieving it. The essays are organized by the themes of: (1) historical perspectives on scientific creativity; (2) neurological and psychological views; (3) science and human values; (4) educating for creativity; (5) toward a theory of scientific creativity; (6) science and the arts; and (7) case studies and personal accounts. Keynote speeches are included on such topics as imagination, the genesis of atomic physics, modern science and pantheism, life and mind in the universe, and why machines cannot do science. Also reported are two pre-conference events that highlighted science in pictures and poetry on science. (ML)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED271298

Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

● Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

Diana DeLuca

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Essays on *CREATIVITY and SCIENCE*

Papers delivered at a conference held
in Honolulu, Hawaii March 23-24, 1985

Edited by
Diana Macintyre DeLuca

Published by the
Hawaii Council of Teachers of English
1986
Honolulu, Hawaii

Library of Congress Cataloging-in-Publication Data

Essays on creativity and science

Proceedings of the Creativity and Science
Conference.
Bibliography: p.
Includes index.
1. Creative (Literary, artistic, etc.)–Congresses.
2. Creative ability in science–Congresses.
3. Creative ability in medicine–Congresses. I. DeLuca,
Diana Macintyre. II. Hawaii Council of Teachers of
English. III. Creativity and Science Conference (1985 :
Honolulu, Hawaii)
BF408.E87 1986 153.3'5 86-4845

© 1986 by the Hawaii Council of Teachers of English
45-720 Keaahala Road • Kaneohe, Hawaii 96744

This Program is
Supported In
Part By A Grant
From The
HAWAII COMMITTEE FOR THE HUMANITIES
A Public Program of the
NATIONAL ENDOWMENT FOR THE HUMANITIES

Contents

Foreword v
Opening Remarks by Albert J. Simone, President, University of Hawaii vii
Preface ix

Keynote Address: *Life and Mind in the Universe.* George Wald 1

Historical Perspectives on Scientific Creativity

The Present Demechanization of the World View. Milič Čapek 17
Reasoning to New Theories. Lindley Darden 25
What is Revolutionary About the Copernican Revolution? Werner Diederich 31
Intimations of Rationality. H. R. Post 43

Neurological and Psychological Views

Creativity and the Behavioral Sciences. Ronald Gordon 53
Science, the Creative Process, and Brain Hemisphere Function. Elaine Kleiner 62
Neuropsychological Study of Talent. Loraine Obler 68
Linguistic Creativity. Wayne Owens 73

The Sciences and Human Values

The Unity of Creativity and its Significance to Science and Social Progress. Alfred Kracher 81
Philosophy, The Nature of Space Science, and the Justification of Space Exploration. Gonzalo Munévar 89
Science, Humanities, and Illusory Bridges. David Paxman 97
Toward a Definition of Creativity. Richard Penaskovic 102

Keynote Address: *The Imagination in Action.* Leon Edel 111

Keynote Address: *The Genesis of Atomic Physics and the Biography of Ideas.* Arthur I. Miller 124

Educating for Creativity

The Science Place. Glenn Leto and Christopher Chiaverina ..137
How Not to Teach People to be Good Scientists.
Peter Manicas 142
Maintaining the Dialogue: General Education at Colgate University. Christopher Nevison 150

Toward a Theory of Scientific Creativity

Creativity in Experimental Science. Tyrone Lai 157
Scientific Unification Through Metaphor. Daniel Rothbart ..163
On Creativity and the Structure of Science. Paul Tang 167

Science and the Arts

Art and Science: Creation or Discovery? Sharon Bailin 175
Aerial Perception. Margret Dreikausen 181
Order, Process, and God. James Huchingson. 187
The Inside of the Human Outlook. Daniel Noel 194

Keynote address: *Modern Science and Pantheism.*
Harold Morowitz 203

Case Studies and Personal Accounts

Creativity in Medicinal Chemistry and Biochemistry.
Alfred Burger 211
Creativity in Science: A Personal Account.
George Greenstein 217
The Rationality of Creativity in Science. Mark Johnson
and Nancy Tuana 225
Exploration of the Mind. M. R. Raju 236
Creative Science Teaching. Claudia Melear 242
Engineering and Humane Values. . George Curtis,
Robert de Loach, Pat Takahashi, and Frank Watanabe ...247

Plenary Address: *Language Theory and Darwinian Theory.*
Gillian Beer 255

Keynote Address: *Why Machines Cannot Do Science.*
Lenn E. Goodman 269

Accompanying Events 283
Science in Pictures. Diana M. DeLuca 285
Poets on Science. Joseph Stanton and Tony Quagliano 287

Biographies 297
Acknowledgments 303
Author Index 307

Foreword

This volume contains the edited proceedings of the Creativity and Science conference held in Honolulu March 23-24, 1985. This volume and the conference that produced it mark the completion of three years of extensive planning and cooperation among Hawaii's educational, legislative, cultural, and business organizations. Beginning with an idea on the Windward Community College campus in Kaneohe, Hawaii, the conference shortly attracted the primary sponsorship of the Hawaii Council of Teachers of English and the cosponsorship of eleven other groups. These organizations are acknowledged with thanks in the Acknowledgments section of this volume. Without their assistance, a conference such as this could not have been conducted.

The broad support of the cosponsoring agencies was echoed in the diverse and generous support granted by the funding agencies. Primary funding was granted by the Hawaii Committee for the Humanities, a public program of the National Endowment for the Humanities. Further support was received from Atherton Trust, Exxon Corporation, the Faculties of Arts and Humanities; Language, Linguistics, and Literature; and Natural Sciences at the University of Hawaii's Manoa campus, Foodland Supermarkets, Hawaiian Electric, the Honolulu Advertiser, Sigma Xi: National Science Honor Society and Sigma Xi: Hawaii Chapter, and the University of Hawaii Foundation. In addition, a number of other Hawaii businesses contributed to the conference and are gratefully listed in the Acknowledgments section.

From its conception, the Creativity and Science conference was designed to be interdisciplinary and to be available to a broad cross-section of the community as well as to educators. The call for papers sent out in early 1985 invited humanists and scientists to submit proposals for presentations dealing with creativity in the humanities and sciences. Responses were received from distinguished international scholars, representing many academic disciplines. From these proposals the program was established by the Conference Program Chairman, Lenn Goodman, Professor of Philosophy at the University of Hawaii Manoa Campus.

Despite the great diversity of backgrounds, the presentors displayed common threads in their discussions. Most agreed that creativity is inexplicable in both the humanities and the sciences, that it comes unexpectedly and cannot easily be rationally explained, and that both humanist and scientist must have prepared minds for those moments when it does appear—just as likely in the shower as it is at a desk or in the laboratory. The keynote speakers addressed these issues from different vantage points. George Wald spoke of the necessity of play if we are to understand a conscious universe that we alter by our presence in it. Gillian Beer described the creativity that arises when two fields overlap and the methodology of one enriches the other—her example the effect of Darwinism on the growth of linguistic theory. Arthur I. Miller found creativity occurring when a rapidly developing field, such as quantum physics in the early part of this century, demands accommodation between what is known and what is coming to be. Harold Morowitz discussed the redefinition of the world that comes about as our worldviews change and alter forever our relation to the universe. Drawing on his experience in writing biographies, Leon Edel talked of creativity as a flash of unconscious insight, as intense as it is revelatory. Lenn Goodman described creativity as uniquely human, basically irreducible to any formula, and an absolute requirement for any scientific or humanistic achievement.

In each panel discussion, the presentors grappled further with the notion of creativity. One panel considered historical examples of changing worldviews that stimulated new discoveries. Another panel focused on the biological roots of creativity and explored the implications of current brain research. Other panels considered what encourages creativity, how best to form the curriculum to encourage it in students, and how it is manifest in science, the fine arts, and literature. One panel shared the mystery and delights of personal experience in making discoveries. In keeping with this diversity of background and approach, the format of these panel papers has been left in the style and documentation system current in the discipline of each presentor.

Perhaps happily, creativity remains as mysterious as ever despite all the discussion. The presentors agreed that it is desirable, that it flourishes under certain conditions, and that one can prepare for it but not instruct or be instructed in achieving it. Creativity is as essential to the scientist as to the humanist, the presentors agreed, and they joined in calling for education to avoid discouraging it by overemphasis on rules and procedures.

Diana M. DeLuca
Project Director
President, H.C.T.E.

Opening Remarks

It is a particular pleasure to acknowledge the participants of the Creativity and Science Conference, especially since the conference represents many of the areas to which the University of Hawaii plans to devote energy in the coming years. It is good to see the evident cooperation between the community colleges and the University's Manoa Campus, and between the University, the State Legislature, the Hawaii Committee for the Humanities, and the numerous community groups and organizations that have contributed time and money to support this meeting. It is good also to see the gratifying response of our community in attendance. The University wishes to forge closer links with the community and our sister educational systems. A conference such as this provides the first step and one that we know will lead to others.

I must salute also the theme of this conference: Creativity and Science. Our state depends upon the creativity and genius of its future humanists and scientists. The young minds we train today will be the ones to take us into the further reaches of space, beneath the oceans, and deeper into the very nature of life itself. They must be able to interpret and evaluate their progress. They will be asked to solve problems and accept challenges as yet undreamed. We owe it to them to keep ourselves fresh and creative and conscious of the need to facilitate their insight and joy in learning. This conference will surely provide a stimulus for all of us, and it will remind us of our own excitement in the educational process.

Hawaii is the gateway to many nations, and our international visitors to this conference are very welcome. The University wishes to further such cooperation among nations and has on many occasions sought to encourage it. I can speak here of astronomy, agriculture, and marine sciences among so many others.

Finally, I would like to acknowledge the Hawaii Council of Teachers of English, the primary sponsor for this conference, and the Hawaii Committee for the Humanities, the primary funding agency. I know I can speak for the participants in expressing appreciation to them and to all the other individuals who have worked for the last two years to make this meeting possible. I should like to echo the words of the unanimous resolution passed by the House of Representatives and "honor and commend" the organizers for a conference that will "enrich our community by bringing together distinguished scientists and humanists and the public to consider the elusive quality of creative thought."

Albert J. Simone
President,
University of Hawaii

Preface

The present volume reassembles the proceedings of the international conference on Creativity and Science held in Honolulu in March of 1985. The printed page cannot recapture the sparkling spontaneity of George Wald or the urbane delivery of Leon Edel, the engaging warmth of M. R. Raju, Alfred Burger or Milič Čapek, or the low key humor of George Greenstein. Some forty speakers from North America and Europe representing almost as many diverse cultures, backgrounds, disciplines and methodologies came together on the gem-like campus of the Mid-Pacific Institute in a lively interchange of ideas which proved to be a milestone in their lives and in the lives of more than 600 participants in the plenary and panel sessions of the two-day conference.

Historians and philosophers of science, scholars of religion, literature and art, philosophers, innovative educators, psychologists and scientists representing many disciplines came together to talk on many levels, the limpid scholarship of Gillian Beer criss-crossing in conversation with the penetrating analyses of Arthur I. Miller and the passionate expostulations of Daniel Noel. The speakers who assembled in answer to our invitations and call for papers were of all ages and stages of seniority. Each one makes an original contribution to the dialogue we had hoped to engender. Our plan was to demonstrate the areas of constructive interaction between the sciences and the humanities, on the meeting ground of the common investment of all exploratory disciplines in human creativity. It was our hope that the impact of these conversations would be felt in classrooms and laboratories as well as in the thinking of all those who listened and who spoke. That there were some grounds behind this hope was demonstrated in the moving tribute paid to the conference organizors and speakers by the unanimous resolution of the Hawaii State legislature, by the generous support the conference received from public and private agencies at the state, local, and national levels, and above all by the warm and lasting responses the sessions met with from students, colleagues and friends, teachers, researchers, community leaders and thoughtful members of the public. It is in the interest of serving that response and perpetuating, extending and deepening the integrative responses which it answers, that we have sought to maintain the record of the conference, carefully edited by the hand of the Conference Organizor, Diana DeLuca. If readers find the thoughts assembled here to be of value, we hope that they will continue the discussions here begun. If they find anything problematic, we hope that they will pursue the issues further. For we do not claim more than to have made a beginning.

L. E. Goodman
Principal Humanities Scholar
Conference Program Chair

Keynote Address

Life and Mind in the Universe

George Wald

I have a rather strange story to tell you this morning, and I wish there were more time for it. But I have to take a moment from the time I have because these introductory remarks that we've just heard bred a comment in me: the exciting seventeenth-century revolution that produced modern science shortly afterward produced the Industrial Revolution, which in a trivial two hundred years has brought the human race to the brink of self extinction. And here we are to talk of creativity. But all of us are those—if you'll forgive me—maimed products of that Industrial Revolution, and I think the force that operates most strongly against creativity is productivity.

I come toward the end of my life as a scientist facing two great problems. Both of them are rooted in science. I approach both as I think would only a scientist, and yet both of them are irrevocably, forever I believe, unassimilable as science. That's not to be wondered at because one involves cosmology and the other consciousness. I'll begin with the cosmology.

We know now that we live in a historical universe, one in which not only living organisms, but stars and galaxies are born, mature, grow old, and die. There is good reason to believe it to be a universe permeated with life, in which life arises wherever the conditions exist that make it possible. How many such places are there?

Well, we have Arthur Eddington's old formula: ten to the eleventh power (10^{11})—that's one hundred billion—ten to the eleventh stars make a galaxy, ten to the eleventh galaxies make a universe. Our own galaxy, the Milky Way, has about ten to the eleventh—one hundred billion—stars. There are just over four billion people on the earth and some of us are beginning to feel crowded. But there are one hundred billion stars in just our home galaxy, the Milky Way. And the lowest estimate we would take seriously of the fraction of those stars in the Milky Way that should have a planet that can support life is one percent. That's about a billion such places, just in our own galaxy. With about a billion such galaxies already within reach of our best telescopes, that gives us as the lowest estimate at least something of the order of a billion

billion—ten to the eighteenth power—places in the already observed universe that can support life.

We find ourselves in a peculiarly life-breeding universe. If any one of a considerable number of the physical properties of our universe that we know were other than it is, then this universe might exist, might be stable, but life would have become impossible in it, here or anywhere.

This universe is made of four so-called elementary particles—protons, electrons, neutrons, and photons—which are particles of radiation. I neglect the neutrinos; they do not interest us here since they do not interact with matter. The only gloss one need make to such a simple statement is that the first three of those particles, the protons, electrons, and neutrons, exist also as anti-particles, the particles constituting matter, the anti-particles constituting anti-matter.

As we look quite far out into this universe we cannot as yet be wholly sure that what we are seeing is matter rather then anti-matter. All our observations are made with photons, with radiation, and photons don't care. They don't discriminate. They are, as we say, their own anti-particles.

About thirty years ago, I was giving the Vanuxem Lectures at Princeton, and Albert Einstein was so good as to come. We walked up and down the street chatting before the first lecture. He turned to me and said, "Why do you think that all the natural amino acids are left handed?"

Those of you who don't know about these amino acids, they can come in two shapes that are mirror images, left (L-) and right-handed (D-). All the natural ones are left-handed (L-).

I had my mind on the coming lecture and just mumbled something.

Then he said, "You know, I've wondered for many years how the electron came out to be negative. Negative, positive, those are perfectly symmetrical concepts. So why is the electron negative? I've thought about this a long time and all I can think at last is, it won in the fight."

I said, "That's exactly what I think about these L- amino acids. They won in the fight."

The fight that Einstein was talking about was the fight between matter and anti-matter. And now I must tell you the first of many strange things.

A few years ago at the Bell Laboratories in New Jersey, two men, Penzias and Wilson, discovered a radiation that had not been known before though there had been some prediction that it would exist. It was a very cold radiation, radiation that represents something less than three degrees above absolute zero. It permeates the universe. It comes from all directions and goes to all directions. It is the fundamental radiation that travels in this universe, and it turns out that there are a billion times as many photons in that radiation as there are particles that we call matter. The matter is only one part in a billion of that radiation. The nicest thought is this: as Einstein said, positive and negative are perfectly symmetrical. So matter and anti-matter are perfectly symmetrical. The neatest idea would be that if one were going to start a universe in the Big Bang, one would start it with exactly equal amounts of matter and anti-matter. Of course, the big principle is that if matter makes contact with anti-matter they mutually annihilate one another and come out as radiation. In that primitive fireball of the Big Bang, with the matter and anti-matter all packed together, there must have been a fantastic explosion of mutual annihilation, and all that should have come out at the end is radiation. But the idea we have is that there was a little mistake in the equality, of one part in one billion. And when all the mutual annihilation had finished, one part in one billion remained, and that's the matter of this universe.

Now I am going to just sample what is a longer argument, and to give the sampling some structure I shall meanwhile climb up the scale of states of organization of matter. So I'll begin with the elementary particles.

I want to say two things about protons, neutrons, and electrons. First—their masses. The nuclei of all atoms are made of protons and neutrons. These are both almost two thousand times the mass of the electron: 1,845 when I last looked. The five is uncertain. So almost two thousand times. The result is that the nucleus of an atom is so much heavier than those electrons weaving around it that its motions are not at all disturbed by whatever the electrons are doing. So an atom can take and hold a position. The position of an atom is the position of its nucleus regardless of what its electrons are doing, and it's only for that reason that we can have solid matter in the universe. If those particles that made up the atoms were anything nearer in mass, whether both heavy or both light, they'd revolve around each other. Nothing would stay put, nothing would be fixed. One couldn't have crystals. It's doubtful whether one could even have chemical combinations, surely not the big molecules that are the heart of our own construction.

I want to say something also about the charges on these particles. The electron and the proton—the proton, of course, plus-charged, the electron minus-charged (and so unlike in mass and every other regard)—have exactly numerically equal charges. That is, the proton is as exactly as plus as the electron is minus. How come?

It will help you to accept this as a legitimate question if I tell you that two of the most distinguished astro-physicists we have, R. A. Lyttleton and Herman Bondi, both in London, in 1959 published a long paper in the *Proceedings* of the Royal Society of London, proposing that, in fact, the proton and the neutron differ in charge by an infinitesimal amount: $2\times10^{-18}e$,where e is the tiny charge on either the proton or the electron. Two times ten to the minus eighteenth: that's two billion billionths. Your first thought is, Who gives a damn? But they explain that with that almost infinitesimal difference in charge, all the matter in the universe would be electrically charged, and in the same sense plus or minus; and since like charges repel, all the matter in the universe would repel all the other matter. So the universe would expand, as all of us believe that it is doing. The only trouble is that as far as I can see (and I've corresponded with both these gentlemen) it wouldn't do anything else. It would expand, yes, but nothing else. And even that almost infinitesimal difference in charge would be enough to overwhelm all the forces of gravitation that bring matter together in our universe. So we would have no galaxies, no stars, no planets, and worst of all no physicists.

Let me go a step up to atoms, to elements. Of the ninety-two natural elements, ninety-nine percent of the living material we know is made of just four: hydrogen, oxygen, nitrogen, and carbon. Why? Those four elements possess absolutely unique properties not repeated by any other elements in the periodic system of the elements. And those happen to be the properties on which the existence of life depends.

Biology professors tell their students foolish things, which the students carefully learn and reproduce on exams and eventually teach the next generation. Chemistry professors do that too. When one teaches the periodic system of elements, one has those horizontal periods of the elements and the professors say, "If you go down vertically, the elements repeat their same properties." That's just utter nonsense, as any kid with a chemistry set would know. For under oxygen comes sulfur. Try breathing sulfur sometime. Under nitrogen comes phosphorus. There isn't any phosphorus in that kid's chemistry set. It's too dangerous. It bursts into flame spontaneously on exposure to air. And under carbon comes silicon.

If that chemistry professor were talking sense, two molecules should be very much alike: carbon dioxide, CO_2, and silicon dioxide, SiO_2. Well, in carbon dioxide the central carbon atom is attached to both of the oxygens by double chemical bonds: $O=C=O$. These double bonds completely saturate the combining tendencies of all three atoms; so carbon dioxide is a fine, happy, independent molecule. It goes off into the air as a gas and dissolves in all the waters of the earth; and those are the places where living organisms ultimately find their carbon. But silicon (I was never taught this by my chemistry professors but found it in a book many years later, so perhaps if you've studied chemistry you haven't been taught this either) cannot form a double bond. Out of all the ninety-two natural elements, only carbon, nitrogen, and oxygen have the regular habit of forming multiple chemical bonds. Silicon cannot form a double bond as carbon does, so silicon is tied to those two oxygens next to it by single bonds, $\overset{|}{\mathrm{O}}-\underset{|}{\overset{|}{\mathrm{Si}}}-\underset{|}{\mathrm{O}}$, leaving two half-formed bonds on the silicon and one on each of the oxygens, just dying to combine with something. What are they going to combine with? Nothing other than the next silicon dioxide, and that with the next, and that with the next, and on and on, until you end up with a rock. That's exactly what quartz is. It's silicon dioxides bound to one another to form a great super-molecule that is a quartz crystal. The reason quartz is so hard is that to break quartz you have to break numerous chemical bonds. And that is why silicon is great for making rocks, but if you want to make living organisms you have to use carbon. I could make a parallel argument for oxygen and nitrogen.

Let's go up a step, to molecules. By far the most essential molecule to life is water. No water, no life anywhere in the universe. And water is the strangest molecule in the whole of chemistry. Its strangest property is that ice floats; and if ice did not float, I doubt that there would be life in the universe.

You know that everything contracts on cooling. That's how we make thermometers: a bit of red-dyed alcohol, mercury if you can afford it, put in a capillary tube contracts on cooling, and you read the temperature. Everything does this. So does water, down to four degrees centigrade. But between four degrees centigrade and zero, where it freezes, it expands so rapidly that the ice that forms is lighter than liquid water, and it floats.

Just think what it would be like if water were like everything else—because practically nothing else does this. It's crazy. If water were more regular and just kept contracting as it cooled, that denser, contracted water would keep sinking to the bottom. Freezing, instead of beginning at the top as now, would begin at the bottom, and it would end by freezing the water all the way through. A really big lump of ice takes forever to melt. That would be the end of life on any planet in the universe if it happened once in a million years; and that would also mean a good chance that life would not develop on planets where life had not yet formed.

In my region of the United States, New England, the fishermen wait all winter for the ponds to freeze over. That's the best time to go fishing. They take their fishing equipment in one hand, a bottle of whiskey in the other, and cut themselves a round hole in the ice. Up to that point the fish were getting along fine. These creatures live through winter with no trouble at all. As soon as the warm weather comes, that skin of ice on the surface melts and with that everything's free again.

Let's go a step up, to planets. What does it take for a planet to be suitable for life? Well, it wants to be about the right temperature, about the right size, and to receive the right kind and amount of radiation from its sun. What's the size condition about? Well, you see, it's only the mass of a planet that by gravitation holds an atmosphere. Our planet is big enough, massy enough, to hold the gases of our atmosphere; though it started with lots of hydrogren, ammonia, and methane, lighter gases, which the Earth wasn't massy enough to hold, they leaked away long ago. It's only the rather heavier gases that even the Earth can hold. Mars is too small to hold an atmosphere. You didn't have to spend all that money, my fellow Americans, to find out that there was no life on Mars. There couldn't be any life on Mars. There is no life on Jupiter. Why? Because it's too heavy. It's so heavy that most of Jupiter is a solid atmosphere, and life is difficult in a solid atmosphere.

How about temperature? Life could tolerate any range of temperature that would allow water to remain liquid. No liquid water, no life, as I've told you. As for the radiation, that's an interesting story too. But we won't go into that much, except that I will tell you in passing that for a long time on this planet, living things had to stay under water, because the radiation from the sun contains ultraviolet radiation that's killing. Not only would it kill all living organisms, it kills the really big molecules, the proteins and nucleic acids. But later in its evolution, life developed the process of photosynthesis in green plants, which produces as a by-product, oxygen. I don't know if all of you realize it, but all of the oxygen in our atmosphere was produced by green plants and is kept in the atmosphere only by green plants. Twenty-five miles up, the radiation from the sun turns some of that oxygen into ozone, which forms a layer that won't let the hard, killing, ultraviolet light through. Then life could emerge from under water and occupy the earth and air. The moral of what I've told you about planets is that the overwhelming probability is that any solar system in the universe will have only one planet that fulfills the conditions that support life. In our solar system, ours is that planet. One planet per solar system. There is a faint possibility that here and there two planets might satisfy those conditions, but in general just one.

And now, another step up, to stars. What does it take in a star to have a planet that supports life?

First, its mass. Our sun is just an ordinary run-of-the-mill middle-aged star. It has existed for five or six billion years and, barring accidents, has another five or six billion years to run. But a star twice the mass of the sun would stay put on what we call the Main Sequence (and only Main Sequence stars can have planets that bear life) only about two billion years. It took nearly two billion years for life to form upon the earth. So any star much massier than the sun would probably never have a planet bearing life, no matter what the other circumstances. A star half the mass of the sun would stay on the Main Sequence some forty billion years, instead of the miserable, paltry ten to twelve billion that we're going to get out of our sun.

Finally, there is a cosmic condition. And these things (I hope you understand what I'm saying, and I'm just sampling them very briefly and in a very elementary way), these are very strange things. And I'm about to tell you one of the strangest.

You see, we live in an expanding universe. Everyone has pretty well agreed to that. But there are two forces that work in it. One is the force of expansion, dispersion; the other is the force of gravitation. The force of expansion is powered by the Big Bang. It pushes matter apart after that great explosion, in the midst of which we are still living. The force of gravitation brings matter together, and these two forces are both at work in our universe. If gravitation dominated our universe, after the Big Bang the expansion would come to an end, the matter would begin to fall together again, perhaps ready for the next Big Bang. There wouldn't be *time* for life to arise and evolve. If dispersion dominated the situation, then all the matter would be flying apart ever since the Big Bang, and there'd be no galaxies, stars, or planets. There'd be no *place* for life. We live in a universe in which it's just very lately been realized that those two forces are in exact balance, so that the universe as a whole is expanding wherever one looks, so everything very distant is going away from us. But locally, there are so-called local groups and clusters, where whole clusters of galaxies are held together by gravitation.

For example, our own galaxy, the Milky Way, has a sister galaxy, Andromeda. It's called by astronomers M-31. It's very much like our galaxy but a little smaller. There is also a still smaller galaxy, all part of our smallish local group.

All of you have probably heard that the reason we believe that the universe is expanding is because of the so-called "red shift." The further one looks out into space, the redder the light is, compared to the same sources here on earth. This is believed to be an expression of the so-called Doppler Effect and would mean that the further one looks out from us, the faster distant astronomical bodies are leaving, in all directions. But the first such color shift ever to be discovered, by the astronomer Slipher back in 1912, was not a red shift, but a *blue* shift. Slipher was looking at our sister galaxy Andromeda; he observed a blue shift because Andromeda isn't going away from us, it's coming *towards us* at something like a hundred miles a second. So we find ourselves in a universe in which these forces are in exact balance. And hence, though at large distances everything is uniformly going away, locally large bodies, whole galaxies, are held together by gravitation. That's very strange because those forces could take any value, but they take this exactly equal value.

So to summarize, we find ourselves in a very curious universe. It possesses exactly those properties that breed life. It takes no great imagination or intelligence to dream up any number of other universes that could be perfectly good, stable universes, but lifeless. With so many options, how did it come about that our universe has turned out this way? From our self-centered point of view, that's the best way to make a universe. But I want to know, how did the universe find that out? And that brings me to my next problem, that of consciousness.

Worrying about consciousness was hardly avoidable in someone like me who has spent most of my scientific life studying vision. I learned my business on the eyes of frogs. If you compare, as I've done at length, the visual system of frogs with that of human beings, things are very much alike. The retinas of both have rods and cones, they have the same three fundamental nerve layers, and the nervous connections to the brain are much alike. The pigment rhodopsin in the rods of both frogs and human beings is chemically very nearly the same, and it goes through the same reactions. Things are very much the same. But I know that *I see*. Does a frog see? It reacts to light. So does a photoelectrically activated garage door. But does it *know* it's reacting? Is it *aware*? There is absolutely nothing I can do as a scientist, nothing, to answer that kind of question.

Science has no way of approaching consciousness. I know that I see. I'm glad to believe that all of you who don't happen to be blind can see. You tell me so. That's very helpful, and you give other evidence of your consciousness. I kind of think that all mammals have consciousness. Birds (I have a prejudice about birds) are probably conscious. That business of singing when the sun comes up and goes down, that sounds to me as though they're essentially poetic creatures. But when I get to frogs I worry. And fish even more so. And the last animals whose vision I worked on with my own hands were worms with great big bulging eyes, with everything you could ask for in an eye, and no indication whatever that they were responding to light. Maybe they didn't like being with me.

But, you see, these are all just unfounded prejudices on my part. There is absolutely nothing I can do to give them reality. Some physician convinced President Reagan (who was eager to be convinced) that a fetus in the first trimester has extraordinary feelings and that it suffers untold agony in abortion. That's a lot of nonsense. Nobody knows what another creature feels. There's no way of finding out. It's just utter, utter nonsense. That doesn't bother President Reagan, of course.

But how about that garage door? Does that door resent opening when my headlights flash on it? How about a computer that can beat a human player at chess? Is it elated? Nothing I can do about those either.

Wilder Penfield once said to me, "Once the brain is exposed, I can operate on it with a spoon." That's because once the brain is exposed, it can feel no pain. Penfield had wonderful opportunties to see what went on in the brain of perfectly conscious unanesthetized patients.

For some years he was engaged in a serious attempt to find the center of consciousness. I was talking with him once and said, "Wilder, why do you think consciousness is in the brain? Maybe it's all over the body. Why do you think it's in the brain?"

He chuckled and said, "Well, I'll keep on trying."

About two years later I met him again and he said to me, "I'll tell you one thing. It's not in the cerebral cortex!"

Then the so-called reticular formation was discovered in the mammalian brain stem, which if stimulated seems to wake creatures up and produce awareness. The idea arose that maybe that's the center of consciousness. The trouble with such developments is that one doesn't know whether one is dealing with the machinery of transmission or has found a source. It's as though you had pulled a transistor out of your television set and, since the program stops, concluded that that transistor was the source of the program.

I want to tell you where I come out. You see, it isn't just that nobody has found the center of consciousness, though they've tried a lot. I think it doesn't *have* a center. I think that consciousness, that thing (it isn't a thing), gives us no physical signals to identify its presence or absence. It isn't that consciousness has not been located, *it has no location*. It's a little bit like the very friendly, very respectful controversy between Einstein and Niels Bohr on the meaning of Heisenberg's uncertainty principle. The uncertainty principle is the recognition that one cannot (and this is very apparent with sufficiently small things like an electron or indeed a proton) simultaneously measure accurately position and motion. The more carefully you fix position, the more doubtful is motion, and vice versa. And this is put into a simple formula that any freshman can learn and put into numbers. It's all very simple and direct.

I used to visit Einstein every now and then and have wonderful conversations with him. He was an easy talker, and he'd rear back and laugh, and his belly would shake. He was a wonderful person, like a very merry Old Testament prophet.

Einstein said to me, "Forever is a long time. I have the idea that the day may come when our technology might be up to specifying simultaneously the position and motion of an electron."

Bohr said, "No. This is no technical failure. This is reality. Reality has this property. That electron in fact *does not have* simultaneously an exact position and motion."

And I'm telling you now that's exactly the way I think it is with consciousness. It *has* no location. It will *never* be located.

Up to now I've told you two strange things: (1) ours is a very, very peculiarly life-breeding universe; and (2) consciousness has no location. A few years ago it struck me that these two things could be brought together in the notion that this is a life-breeding universe because the constant, pervasive presence of mind guided it in that direction.

I've been in experimental science long enough to know that when you've done an experiment that comes out surprisingly well, the thing to do is enjoy it, because the next time you try it, it may not work. So when this idea struck me, I was elated. I enjoyed it immensely. But I was also embarrassed. I thought, "My God, Wald, senility is hitting you in a big way." That idea violated all my scientific feelings. But it took only a few weeks to realize that that kind of idea is not just centuries old but millennia old in Eastern philosophies. And numbers of that monumental generation of physicists who filled the earlier part of this century (of whom I knew only two—but they were a good two to know—Einstein and Bohr) came to this kind of thought again and again: that consciousness or mind is not, as I had believed and most biologists tend to believe, a late product in the evolution of life on this planet. You do not have to wait for it until very high levels of consciousness arise. On the contrary, it was there all the time. Mind was there all the time. The reason that this is a life-breeding universe is that the pervasive existence of mind guided it in that direction, and for a reason.

One of the nicest expressions of this thought was given by one of those monumental physicists, Wolfgang Pauli, Swiss, and incidentally in his lighter moments not only a monumental physicist but a mystic. He was very interested, for example, in the Cabala and in the whole of mysticism. The Industrial Revolution wiped out Western Mysticism, which had been going great guns, because it doesn't fit snugly into an industrial society. We tend to think of mysticism now as a flight from reality, whereas William James described it as an insistent attempt to define reality.

Wolfgang Pauli said it most nicely: "It would be best to believe that mind and matter are complementary aspects of all reality."

The word that I need to explain further is *complementarity*. It was introduced as a physical principle by Niels Bohr, and it involves the realization that I think all of you are aware of: light and radiation—in fact all elementary particles—have the properties of both particles and waves. You must understand that those are mutually exclusive properties. A wave is as different a thing as can be from a particle. Yet all these very small units have both sets of properties, and one has to live with both sets. And now I want to add another realization.

Biologists are rather uncomfortable with the idea of consciousness, because they feel this is a property of living organisms, and hence they ought to know about it and be able to tell the physicists about it; whereas they have nothing whatever to say. But physicists live day in and day out with the problem of consciousness. The very nucleus of twentieth-century physics is the realization that, as opposed to nineteenth-century physics and much twentieth-century biology, the observer cannot in fact remove himself from what he is observing so as to view it objectively. Every good physicist knows that he enters into every physical observation.

I'll give you a simple example. I already spoke of the wave and particle properties of light, or any radiation. Well, as I say, they're mutually exclusive. Enter consciousness—the physicist about to do an experiment with light, for example, decides which set of properties he will find. If he does a wave experiment, he gets a wave answer. If he does a particle experiment, he gets a particle answer. He decides beforehand which of those sets of properties he will find. Every physical observation is subjective.

I'd like to say just a word (I'll put it foolishly because there's no time to put it better) about consciousness: if mind was in the universe all the time, why did it bother to make matter? And as I told you at the very beginning, matter just made it. One one-billionth of the stuff that went into the Big Bang remains the matter of this universe. But why bother?

I think the answer is (and this is terribly serious in this utterly sad and increasingly violent world we live in) that with life permeating this universe, in various places it gets to make creatures like us. We are the art- and science- and technology-making creatures. Such creatures form societies; and these societies produce language, writing, and literature. This means that a new and independent evolution of consciousness becomes possible.

Our physical and physiological beings are the product of an evolution, the driving force of which is what Darwin called natural selection. It has three components: (1) a ceaseless outpouring of variation; (2) some mechanism of heredity; and (3) a kind of competitive principle, the struggle for existence, in which organisms and their properties that work better are retained and those that work less well are discarded.

Societies produce cultures that display all three of these characteristics: on the one hand, a constant outpouring of variations; on the other hand, mechanisms of inheritance, but now of *cultural* inheritance (for those of you who are biologists, cultural inheritance is not genetic but Lamarckian—it involves entirely the inheritance of *acquired*, learned characteristics); and finally a constant rubbing of one culture on another so that cultures rise and fall, survive, and become extinct.

So I would suggest that why mind took the trouble to make a universe of matter and one that breeds life, is that out of life here and there come these creatures that begin to know and make possible a new and independent evolution of mind, parallel with and superimposed upon the ongoing evolution of anatomy and physiology. There is an enormous ambiguity between *being* and *being known*. I ask you, can anything be and not be known? Recognition is itself a kind of creation.

And now let me say a few words about creativity.

First of all, everything I said about the characteristics, the physical properties that make this a life-breeding universe, apply also to making this a more varied, more innovative, indeed a more creative universe. Everything I've told you, and ever so much more that goes into the story of why this universe can breed life, contributes also to this being a more varied, innovative, creative universe.

The thought that consciousness has no location opens a wide door. The door is opened still more widely by yet another of those monumental physicists, Erwin Schrödinger, who gave us the wave mechanics. In a book called *What is Life?*, in the last chapter he calls "Epilogue," Schrödinger raises the question, are we not perhaps mistaken in thinking that there are as many minds as there are bodies? There are clearly lots of bodies, but perhaps many fewer minds, perhaps indeed only one mind. Schrödinger explains that he'd been interested for many years in the Eastern philosophies, in which that's an implicit kind of idea. In Hinduism the name of that universal mind would be Brahman; and the self, Atman, contains in part and shares in the Whole, which is Brahman. So, a wide door. What would happen if one went through that door? Well, I recommend a book to you, which I never would have picked off the shelf. But a friend I respect enormously sent it to me, and I read it with great excitement. It's *Sri Aurobindo: Or the Adventures of Consciousness*, by Satprem. You see, I think that genuine mysticism actually is just an invitation to explore. It's not starting to attach oneself to a cult. It's an invitation to explore, and it has a property that all of us scientists are so proud of in science: it's entirely experimental, entirely empirical. No one can tell you how far you will go or what you will find. That's up to you to find out. That's the adventure of consciousness, and that is the door that this opens. And I'll give you a good material, practical possibility that exists in this. It is that that universal mind, which Schrödinger and indeed all the mystics have suggested, could possibly constitute—if you try—a communication system that you wouldn't have to pay the telephone company for.

I came to India for the first time ostensibly to attend the All-India Science Congress in Bangalore. I really went to visit India. As soon as I had arrived at the Science Congress I was asked to go to New Delhi for a three-day meeting on consciousness. I'd never been at any such thing in my life. It was a small, good meeting—just a group of about fifteen people sitting around a table. For the first two days I listened intently, and I was astonished to realize that a number of people were talking about something they called super-consciousness, something of a higher order than what most of us tend to experience. Everyone has heard endlessly, "Oh yes, we use only a tiny fraction of our brains." That's what I'm talking about, except that, as I have said, it goes on outside the brain. So there was a lot of talk about super-consciousness, and what was being said was, We need better higher education. We need to produce a new system of education that will produce super-consciousness instead of the lesser consciousness that we have.

On the third day, when I had a chance to speak, I said that I was astonished by this, and I thought the situation was quite different. I thought that what they were reaching for lay not ahead of them but behind them, racially in what we tend to call more primitive societies, including our own of long ago, and individually in our childhoods.

You know, an American kid, up to say eight or nine years of age is living out there in the universe. If you provide the materials, this child will paint you a very interesting picture. If you provide other materials, you will get an interesting sculpture. The child dances, sings, shouts, hardly dividing dreams from the waking world. Then at about eight years of age in our society, the whole society goes to work on that poor kid—the parents, the schools, the churches, the whole society. That child is told, "It's time to stop playing and learn to work." And that child is put on a track to the great satisfaction of the parents, because when you are on a track you are going somewhere. See? And there are stations, and there's a schedule. See? The only trouble is, you're not going anywhere else. And one says essentially to that kid, Why sing? You're not going to be a singer, are you? Why paint? You're not going to be an artist, are you? And that child is turned into our kind of person. Taken out of life in a sense in order to make a living, which is a very different thing.

I think that this may be a profoundly traumatic experience. The most mysterious thing I know, bar none, is the way that people forget their early childhoods. My God! A three-year-old kid, a four-year-old kid is a *mensch!* You know, talking all the time and thinking and imagining and making and doing. Then at age twenty, thirty, forty, you ask that person, How far back can you remember? It's usually not as far back as four. That whole passionate, wonderful life has been wiped out.

I think we are all those traumatized people. As for creativity, the very heart of it is play. Play. Playing *is* creativity, and any scientist or artist or academic who has stopped playing can only hack thereafter. Play is infinitely important.

Panel Topic

Historical Perspectives on Scientific Creativity

The Present Demechanization of the World View

Milič Čapek

The term scientific revolution is now frequently used, perhaps too frequently. But if there is any phenomenon to which it can be rightly applied, it is the development of physics in the twentieth century. Never in the past, not even in the famous cosmological revolution in the sixteenth century, were the changes in our overall view of the world so profound and far-reaching. It is not easy to characterize these changes by a single term since such a term is unavoidably too general and thus misleading. This is also true of the word *demechanization* that I am using. I could equally well use the words *depictorialization* or *devisualization*. To understand the meaning of such terms, allow me to outline briefly the main features of the classical picture of nature. I am using purposely the word *picture* to stress its intuitive or visual character; as we shall see, the two adjectives *mechanistic* and *pictorial*, although not entirely synonymous, are very closely related. In outlining the main features of the classical view of nature, one obtains the contrasting backdrop against which the salient traits of the present upheaval in physics will clearly stand out.

The classical view of nature developed gradually in the last three centuries, i.e., approximately in the period from 1600 to 1900. Needless to say, these limits are only approximate as in the continual stream of discoveries, both empirical and theoretical, all boundaries are artificial. Yet, the dates mentioned above happen to have certain symbolical values: in 1600 Giordano Bruno was burned alive at Rome at least partly because—contrary to Aristotle—he claimed that the universe has no spatial limits. This transition "from the closed world to the infinite universe" (to use Alexander Koyré's expression) was a tremendous step that at the time neither Copernicus nor Gilbert nor Kepler ventured to take; it was a daring anticipation, philosophical rather than scientific, of the most fundamental concept of Newtonian physics, i.e., of the absolute infinite space. In the year 1900 Max Planck formulated the first quantum theory without realizing fully the implications that his constant *h* would have in the subsequent development of physics. But this does not mean that we have the right to overlook the important intellectual events and discoveries that took place before these two dates, such as the beginning of the cosmological revolution in the sixteenth century, which coincided with the publication of Copernicus' book in 1543; nor must we forget the first anticipatory signs of the present revolution in physics in the last years of the nineteenth century, such as the discovery of photoelectric effect and of radioactivity as well as Michelson's and Morley's vain search for the absolute motion of the earth, which clearly indicated that the classical mechanistic view of the world was not as complete as it appeared.

The mechanization of the world view could proceed consistently and systematically only when the foundations of mechanics were firmly established. This was a long process, not completed before Newton. There is no place here to follow it in detail, not even in its main stages; only a greatly simplified sketch can be given. Suffice it to say that the cosmological revolution of the sixteenth century and the beginning of the seventeenth century can be characterized as a *geometrization*[1] of nature rather than its mechanization; the circles of Copernicus and Tycho Brahe were geometrically simpler than the epicycles of Ptolemy or the fifty-five spheres of Aristotle. But the causal mechanism of these motions was as unclear as in the medieval cosmology, in truth even more obscure, as the revolving spheres allegedly carrying the celestial bodies were removed. "Modern science," wrote Henri Bergson in 1907, "is the daughter of astronomy; it has come down from heaven to earth along the inclined plane of Galileo, for it is through Galileo that Newton and his successors are connected with Kepler" (335). This is suggestively and concisely stated, but while it correctly suggests the interaction of astronomy and terrestrial mechanics in what Whitehead called "the century of genius," it should not be taken too literally. For it is not correct to say that the elaboration of celestial mechanics *preceded* that of the mechanics of the terrestrial motions. Neither Copernicus nor Kepler understood the principle of inertia despite the fact that the latter even invented the term; but inertia for him was the resistance of the bodies to every motion, even to its continuation—it was really the principle of conservation of position. He believed, like Aristotle, that every motion requires an external mover.

The obsession with the alleged perfection of circular shapes and circular motions continued. Even Kepler, who substituted elliptical orbits for circles, still retained the finite spherical universe bounded by the celestial sphere "two German miles thick." Galileo himself did not overcome entirely the traditional dualism of the sublunar and heavenly realms as he apparently accepted the natural character of the circular motions of the planets; he failed to divide them into two components—the tangential (inertial) and the centripetal (gravitational). This was done later by Borelli and, in particular, by Huygens.[2] Even to Galileo the full significance of the law of inertia was far from clear, nor were all its implications grasped by Descartes despite all his contributions to its formulations; he still failed to understand it in a *vectorial* sense when he believed that soul has the power to change the direction of physical motion without any expenditure of force![3]

Thus only when all the implications of the law of inertia were known could the foundations be laid for the great Newtonian synthesis. Newton's foundations of mechanics remained intact for more than two centuries; what followed Newton's *Mathematical Principles of Natural Philosophy* was the making explicit of all the consequences implied in the principles he formulated. Ernest Mach cites Gauss in his *Science of Mechanics:* "No essentially new principle," Gauss remarks, "can now be established in mathematics; but this does not exclude the discovery of *new points of view*, from which mechanical phenomena can be fruitfully contemplated [my italics] "(442). The truly new laws of mechanics could be discovered only after the thorough reformulation of the classical axiomatic basis in the twentieth century.

Mechanical explanation became an ideal model of every explanation at the very moment of the birth of classical mechanics. Christian Huygens, who in his *Traité de lumière* tried to incorporate the optical phenomena into mechanics, stated explicitly that "in the true philosophy we conceive the causes of all natural effects in terms of mechanical motions. And, in my opinion, we must admit this or else give up all hope of even understanding anything in physics"(3). Basically, this was the Cartesian ideal of explanation "*par les figures et les mouvements*" and as such it dominated physics undisputed for more than two centuries. In 1884 William Thompson restated it in nearly identical terms: to understand a particular topic in physics coincides with our ability to *make a mechanical model* of it. Considerable nostalgia for mechanistic explanation can be found even among outstanding physicists of this century; even the great Hendrik Lorentz was very reluctant to give up the classical concepts, including the mechanistic model of ether, despite enormous difficulties and even contradictions inherent in it.[4]

This process of mechanization is described in a documented way by E. J. Dijisterhuis in his book, *The Mechanization of the World Picture*. But his description is confined to seventeenth-century physics only. Nevertheless even then this type of explanation transcended the boundaries of physics as it was gradually applied to biology and even psychology. Since the cornerstone of the seventeenth-century philosophy of nature was the concept of the unity of nature in both space and time, it was recognized very early—and not only by materialists such as Hobbes—that there is only a *difference of degree* *between organic and inorganic matter.* Harvey's hydrodynamical explanation of the circulation of blood, earlier regarded as the very essence of the "vital principle," was in the year 1628 the first success of mechanistic biology. Again there is no place here to give even a very rough sketch of this process and its various stages, such as Lavoisier's explanation of breathing by oxidation, the first synthesis of urea by Wöhler two centuries after Harvey, the emergence of organic chemistry in the last century, and the discovery of the genetic code in this century. Furthermore, the concept of unity of nature *in time* was the basis of the assumption that the natural processes in the past did not differ essentially from those in the present; this was the central idea that brought the sciences of cosmogony, geology, and evolutionary biology into existence, including Darwin's mechanistic explanation of the origin of species.

Philosophy rarely anticipates the development of sciences, but no attentive historian of ideas can deny that the main features of the mechanization of the world view were anticipated by the philosopher-scientists of the seventeenth century. Obviously, there were differences between them: Descartes and Hobbes favored what Kurd Laswitz, a historian of atomism, called "the fluid theory of matter" that fills space continuously; Gassendi and the atomists in general insisted on the reality of the void, separating their particles. The opposition of these two views persisted through the whole classical period. But these were relatively minor differences within the larger mechanistic trend, which included, as we said, the incipient mechanization of biology and even psychology. Modern behaviorists would certainly applaud Descartes' denial of consciousness in animals. What is less known is that Spinoza in the epilogue to the first book of his *Ethics* formulated very accurately the basic principles of mechanistic biology at least in its main features: the insistence on the strict causal explanation and its corollary—the elimination of any non-physical, teleological principle as well as the negation of any objective ethical and aesthetical distinctions, which he regarded as subjective as the secondary qualities. In this respect, he was more consistent than Descartes who remained interactionist despite his mechanism.

Yet even then there remained one residuum, which mechanism was never able to assimilate: *the very fact of consciousness,* or, more concretely, of *mental qualities*—thoughts, feelings, sensations. But this residuum was of fundamental importance since it is epistemologically prior to any conceptual constructions. Descartes' *cogito* can be rephrased in various ways: Mach preferred to replace it with "it thinks" (*es denkt*) and John Dewey followed him in this respect.[5] Bergson retained it while desubstantializing it ("I think therefore *I become*" instead of "I think therefore I am"). Santayana, who denied nearly all certainties, nevertheless retained "solipsism of the present moment." After Descartes, and especially after Kant, a simple-minded materialism was regarded as incompatible with the most elementary epistemology; this is why it vegetated only on the periphery of philosophy, among physicians, rank-and-file scientists, and Marxist agitators. This was at least the situation in Europe; if materialism in the form of behaviorism dominated psychology in America, it was because of its complete separation from philosophy and, more specifically, epistemology.

Still, this situation was understandable, as in the impressively successful mechanistic scheme consciousness appeared as a strange anomaly, a sort of "ghost in the machine," to use Gilbert Ryle's words. This is why any defense of interactionism appeared so implausible and unconvincing. Interaction implied contingency and/or freedom; but there is no such thing in the mechanistic universe, as the determinists of all ages, from Spinoza to Laplace were never tired of pointing out. Some more sophisticated naturalists retained the existence of consciousness but stripped it of any causal efficacy, viewing it as causally inert "epiphenomenon."

The situation today after a dramatic decline of mechanism in physics is very different. Within the assigned time limits I can give only a very general and overconcise outline of the philosophical impact of contemporary physics, which I have treated more thoroughly in my books and articles.[6] All component parts of the classical picture of the physical world, i.e., all concepts of classical physics, were subject to a radical, revolutionary revision. These concepts were as follows: space, time, matter, energy, motion, and causality. Space of classical physics was Euclidean, consequently homogenous and independent of time; this was regarded so obvious that Kant viewed it as the result of a priori structure of our mind. In the light of relativity theory this is not so: it is closely united with time, its structure is not Euclidean, and even its infinite divisibility is in doubt in light of quantum theory. This junction of space with time inevitably affects also the structure of the latter. Time is no longer a uniformly flowing river as Newton believed, and it is impossible to make instantaneous cuts in it that would correspond to the universal cosmic "nows." This is the meaning of the relativistic denial of absolute simultaneity. The doubts about the continuity of time are now as strong as those about the continuity of space and for the same reasons. The concept of matter was also profoundly modified. While in the classical view, matter was contained in space and time, today the distinction between the chrono-geometric container and its physical content is considerably dimmer, if not altogether eliminated;

according to the general theory of relativity, the gravitational field is not in space, being nothing but a local irregularity of non-Euclidean space, or rather space-time. Mass itself is merged with energy and two separate laws—one for conservation of mass, another for conservation of energy—are fused into one single law of conservation of mass-energy. This had some consequences particularly shocking for our pictorial imagination, such as the so-called creation and annihilation of microparticles. It is true that their creation is not ex nihil since they are born out of a high frequency radiation; nor is their destruction ad nihilum since their energy reappears in that of photons. But while this makes the process intellectually more palatable, it remains completely incompatible with the classical concept of the immutable, everlasting particle that from Lucretius to Dalton was a cornerstone of atomism. In truth, the very word *particle* is a misnomer, if only because the duration of some of them is so vanishingly short that it is far more appropriate to call them "events." They certainly are not microsubstances in the classical sense.[7]

The mechanistic picture of the world was an all-embracing *vision* of the world, a vision in its *etymological* sense as it consisted mainly of visual elements. When all its component parts were transformed beyond recognition, it should not be surprising that the very meaning of its vision—the strict determinism implying a complete predetermination of the future—is in doubt. Still, the discovery of microphysical indeterminacy, although it followed from the indivisibility of Planck's action *h*, came as a real shock to philosophers, not only to naturalists and positivists, but even to Neokantians and idealists who remain under the spell of Newtonian physics and Kant's Newton-inspired *Critiques* more than they realize. It is still possible to hope that the crisis of classical causality is only temporary and that new discoveries on the sub-quantum level will restore determinism. So far this remains only a hope. In any case, the claim that to admit the reality of contingency is equivalent to "suicide of reason" is based on a rather narrow traditional view of rationality. On the contrary, the "open universe"—to use the words of both Weyl and Karl Popper—is far less absurd than the old universe of Laplace, which in denying any genuine creativity and transforming cosmic history in a mere unfolding of prerecorded pattern, made the very existence of time unintelligible and reduced consciousness to a useless luxury of nature, a ghostly entity entirely stripped of any causal efficacy. The new dynamic universe envisioned by James, Bergson, Whitehead, and more recently by Weyl and Popper, is in this sense less absurd than the "bloc universe"of rationalism and mechanism.

It is true that the emerging new view (not a picture!) of reality is still in its incipient stage. Its imageless, non-intuitive character probably will preclude the mass influence and popularity enjoyed by its extinct predecessor. A great deal of conceptual clarification has yet to be done. For instance, while it is obvious that the terms *microphysical indetermination* and *freedom* must not be confused, it is equally naive to claim that these concepts are unrelated. (This is usually claimed by those who consciously or semiconsciously are still committed to mechanism.) John Dewey, with his usual penetrating insight, rightly observed that contingency is a *necessary* though not *sufficient* condition of freedom (249).

For as long as we assume that the physical world, including the nervous system, is strictly and in all its details determined, no contingency, a fortiori·no freedom, is possible. Only the existence of contingency, no matter how minute, makes the physical world open to a real efficacy of consciousness, to what Popper recently called "downward causality." In the dynamic universe microphysical contingency, vital spontaneity, and freedom probably represent three different degrees of "emergent causality", i.e., of what William James called "the everlasting coming of novelty into being" or what Whitehead called "creative advance of nature." Such different degrees of causality were proposed by such very different thinkers as Henri Bergson and Norbert Weiner. Only in such a dynamic and pluralistic universe *can* values acquire an objective status; the ethical distinctions, as James pointed out long ago, are meaningless in the old "bloc universe." But let us stress the words *they can*. The existence of the dynamic universe does not necessarily guarantee the objectivity of positive values. Creation does not necessarily mean a creation of positive values.

A mere glance at the last decades shows clearly and depressingly many instances in which evil is deliberately and consciously created. Furthermore, the systems of Sartre and Heidegger show clearly that the emphasis on the dynamic character of existence can go hand in hand with the most extreme forms of both ethical and intellectual irrationalism. Here there is some analogy between social and intellectual revolutions: they both provide for all sorts of excesses. Occurrence of violence and mob rule in revolutions is well known; what is less known is a violent thriving of wild and irresponsible speculations in the period of intellectual revolutions. Here one must be on guard. I am convinced that the demechanization of the world view opens a place for transsubjective, absolute values. But I also realize that a mere opening is not enough.

Notes

[1] A better term probably would be a *geometrical description* of nature, unconcerned about the physical causes of motions: a mere kinematics, no dynamics. In this sense, it was different from Cartesianism, which tried to combine its geometrization of nature—i.e., the identification of matter with space—with a real concern about *the causes* of motions.

[2] On the achievements of Borelli: A Koyré, *La révolution astronomique* (Paris: Hermann, 1961), 462-506. On the significance of Huygens' discoveries: E. Mach *Science of Mechanics*, 195-205. On Kepler's view concerning the thickness of the celestial sphere: J. L. E. Dreyer, *A History of Astronomy from Thales to Kepler*, 2nd. ed. (New York: Dover, 1953), 411.

[3] Descartes recognized that souls cannot impart any force to bodies because there is always the same quantity of force in matter. Nevertheless, he believed that soul can change the direction of motion. But this was because, in his day, the law of nature that affirms also the conservation of the same total direction of motion was not known.

[4] Huygens, *Traité de la lumière*, 3; W. Thompson, *Notes of Lectures on Molecular Dynamics and the Theory of Light* (Baltimore, 1884), 132. On Lorentz's nostalgia for classical concepts, see E. T. Whittaker, *A History of the Theories of Aether and Electricity* (London: Nelson, 1953), 36.

[5] Such depersonalization of consciousness proposed by Mach and Dewey was already opposed by William James, who regarded it as a distortion of the immediate introspective experience: "to personify it cannot possibly be wrong, *it is already personified*. . . . The universal conscious fact is not 'feelings and thoughts exist,' but 'I think' and 'I feel'," *The Principles of Psychology*, I, 226–227 (italics mine). See also my article, "The Reappearance of the Self in the Last Philosophy of William James," *Philosophical Review*, 62 (1953), 526–544.

[6] *The Philosophical Impact of Contemporary Physics* (Princeton: Van Nostrand, 1969); *Bergson and Modern Physics* (Dordrecht: Reidel, 1971).

[7] On this point see my article, "Particles or Events?" in *Physical Sciences and the History of Physics*, eds. R. S. Cohen and M. Wartofsky (Dordrecht: Reidel, 1984).

List of Works Cited

Bergson, Henri. *Creative Evolution*. Trans. A. Mitchell. University Press of America, 1983.

Dewey, John. *The Quest for Certainty*. New York: Putnam, 1960.

Hugens, Christian. *Traité de la lumière*. Paris: Gautheirs Villars, 1920.

Mach, Ernest. *Science of Mechanics*. Trans. T. J. McCormack. La Salle, Ill.: Open Court, 1942.

Reasoning to New Theories: Analogies, Interfield Connections, and Abstract Theory Types

Lindley Darden

As a philosopher and historian of science, I am interested in the reasoning that produces new scientific concepts and theories. A prevailing view in the philosophy of science is that the discovery of new theories is a matter of the individual psychology of the scientist, that there is no "logic of discovery." Karl Popper (1959) is a prominent proponent of this view, and Carl Hempel (1966) argues that there are no mechanical rules for producing the novel concepts found in theories. But two important philosophers of science have countered this opinion. N. R. Hanson (1961) and Mary Hesse (1966) suggest that analogies may play a role in the reasoning to new theories, and Hanson also suggests that one may first reason that a type of hypothesis is plausible before proceeding to construct the more detailed theory. This paper builds on Hanson's and Hesse's suggestions about the use of analogies and reasoning to types of theories.

Although philosophers of science have not found a single logic of discovery, less general strategies for constructing plausible theories have been proposed. The three methods to be discussed are (1) reasoning by analogy, (2) reasoning by postulating interfield connections, and (3) reasoning by use of an abstract type of theory. I will examine cases from nineteenth and twentieth century biology for patterns of reasoning either used by scientists (if evidence exists) or that were sufficient to produce theories whether actually used historically. For a discussion of the search for sufficient patterns of reasoning to rediscover chemical laws—although not ones used historically—via computer, see Langley, Bradshaw, and Simon (1980).

A key problem in understanding the construction of new theories in science is comprehending the source of new concepts and recognizing how they are built into a new theory. Concepts such as natural selection, linked genes, and clonal selection of antibodies have other sources than the data they serve to explain. One suggestion is that they are the product of reasoning by analogy. Reasoning by analogy has been characterized by Mary Hesse as a mapping between a problem domain and a single analog, such as reasoning that light consists of waves by analogy with sound waves.

However, a single analog is sometimes insufficient to construct a theory. Information from more than one area may be put together. This pattern of piecemeal theory construction emerges from Charles Darwin's construction of the theory of natural selection. Historical research has shown that Darwin proposed a number of working hypotheses ("theories to work by" according to Kohn, 1980) in the early stages of his thought. The two areas of investigation that provided him with key ideas retained in the published version of his theory in 1859 were Malthus' ideas about population increase, and ideas about artificial breeding. The relation between Malthus' ideas and Darwin's was not analogical but one of generalization. Malthus proposed that human populations were increasing at a faster rate than food supplies were or could. Darwin generalized this claim to a struggle for existence among all animals and plants.

Thus supplied with a mechanism for eliminating some organisms, Darwin proposed that artificial selection was analogous to natural selection: human breeders selected varieties useful to humans; nature selected those favorable to the struggle for existence. Darwin thus combined knowledge from two different areas of inquiry to construct his theory of natural selection. Neither Malthus' ideas nor the analogy to artificial selection alone was sufficient, but the two combined functioned in the construction of the theory (Darden, 1982).

The theory of natural selection can be characterized briefly: there is inherited variability among organisms; there is a struggle for existence such that not all organisms will survive; over time, new and better adapted forms will replace older ones and give rise to new species. The various concepts within the theory, such as inherited variability and the struggle for existence had different sources. Piecemeal theory construction is a powerful way of putting old things together in new ways (Darden, 1982).

With analogical reasoning, however, there is always the question of whether the analog is appropriate, whether the problem area is sufficiently like the analog that one would expect transfer to be possible. Independent testing of the theory, once proposed, is necessary to determine whether the theory can be supported by data. Interfield connections that are stronger than analogical promise more assurance of successful theory construction.

An example of a successful interfield connection was the postulation of the relation between Mendelian genes and chromosomes (thread-like bodies within the nuclei of cells). Mendelian genetics emerged in the early twentieth century with the use of artificial breeding as an important technique. After genes were postulated to account for the regularities in breeding data, the question arose as to the nature and location of the genes. Cytology was an independent field that developed in the latter half of the nineteenth century, using the techniques of microscopic analysis to study cells, their contents, and their interactions. Cytologists, quite independently of geneticists, developed the hypothesis that the chromosomes carried this hereditary material. In 1903 and 1904 two biologists, Boveri and Sutton, independently brought together the information from the fields of genetics and cytology by proposing that the Mendelian genes were in or on the chromosomes. The chromosome theory of Mendelian heredity was an interfield theory that made predictions from each field on the basis of related information from the other. For example, since there were more genes postulated in a given organism than that organism had chromosomes, the theory predicted that some genes would be linked in inheritance. The prediction of linkage was confirmed. This interfield connection is stronger than analogical: genes were claimed to be *physical* parts of the chromosome. The predictions thus carried more force than predictions resulting from mere analogical relations, which do not postulate physical relations (Darden and Maull, 1977; Darden, 1980).

Some historical evidence exists that scientists do actually reason by analogy and reason by postulating interfield connections. However, another form of reasoning in theory construction has little historical evidence to show that it has been used: reasoning using abstract types of theories. Even though it has not been used extensively, my proposal is that it is a method that deserves to be developed and considered.

Consider the problem that Darwin wished to explain: how do new forms adapted to their environment arise? The problem may be expressed more abstractly: devise a theory to explain how one thing comes to "fit" another. Historically, two types of theories have been proposed to solve such problems. Let's call them "selection-type" theories and "instructional-type" theories. In selection-type theories, one thing becomes adapted to another by selection of the adapted variants out of a larger array of variants. In instructional-type theories, some sort of instruction plays a role to assure that only adapted forms are generated. To explain adapted organisms, Neo-Darwinism postulated natural selection, whereas Neo-Lamarckism postulated inheritance of acquired characteristics. To explain the fit between antigens and antibodies that destroy them, template versus selection theories of antibody formation were proposed.

The abstract form of a selection-type theory can be characterized as follows: (1) a mechanism generates an array of variants; (2) selection of a subset of variants occurs, according to some criterion; (3) after selection, the pool of variants is different. Subsequent selection steps may occur, using the altered pool of variants.

In the abstract form of an instruction-type theory, an entity is generated according to a criterion. In comparing this with the form of selection-type theories, we see that the criterion of selection has been moved into the generator of the entities, eliminating the need to produce wasteful, nonadapted variants. However, if the criterion changes (e.g., a change in the environment), then the success of the process in incorporating a new criterion will determine whether the entities can adapt rapidly in changing environments.

Neo-Darwinian theory (Darwin himself postulated some inheritance of acquired characters) is a selection-type theory: (1) an array of spontaneous mutations arise (not in response to environmental need); (2) selection occurs as those mutations favorable in the current environment are more likely to reproduce; (3) after selection, the pool of variants is different, with more of the adapted ones surviving and reproducing.

Neo-Lamarckism (Lamarck's theory was more complicated) postulated that organisms respond to an environmental need by acquiring a new characteristic, e.g., the giraffe stretches its neck to reach the higher leaves. Lamarck actually postulated a mechanism by which the perception of the need caused fluids to flow within the body and elongate the neck. Lamarck, as others from the time of Aristotle through the late nineteenth century, assumed that characteristics acquired during an organism's life would, at least sometimes, be inherited by its offspring. Thus the newly acquired characteristics were passed on. Weismann's work and Mendelian genetics served to dispel belief in the inheritance of acquired characteristics, although proposals for this kind of theory continue to appear (Lamarck, 1809; and Steele, 1981).

The body is able to defend itself against invading antigens (foreign molecules) by producing antibodies that are specific to the particular antigen. A very large number of different types of antibodies are made to foreign substances. Linus Pauling and others in the 1940s proposed an early theory of antibody formation of the instructional-type theory: the template theory. It proposed that an amorphous protein was made that would then acquire its final form by being configured by the antigen that it disabled. Thus the antigen provided information in the form of a template for the final stages of antibody formation. Only those antibodies needed to combat current invaders were formed.

An alternative to this theory was proposed by Jerne and developed by Burnet into a selection-type theory: the clonal selection theory of antibody formation. Jerne proposed a random mechanism for synthesizing all possible antibodies and a selection mechanism for promoting additional synthesis of those antibodies that fitted a particular invading antigen (Jerne, 1955). Burnet developed the idea that one cell produces one type of antibody; when an antigen invades, receptors on the appropriate cell surface recognize the antigen and that cell is stimulated to divide. This clone of selected cells provides the antibodies needed to combat the invasion (Burnet, 1957).

In these two historical cases, the theories that were confirmed by subsequent tests were the selection-type theories, natural selection, and the clonal selection theory. It may be that for oganisms in an uncertain world, selection processes provide variability that may enable the organism to cope with the unexpected better than any instructional mechanism is able to do. From these historical examples, we can thus devise a method: when faced with the problem of explaining how one thing becomes adapted to another, consider both instructional and selection theories, keeping in mind that selection theories have historically been more successful.

In summary, we have discussed three patterns of reasoning in theory construction: (1) reasoning by analogy, (2) postulating interfield connections, and (3) instantiating an abstract theory in a particular kind of problem situation. These patterns have emerged from the study of numerous cases from nineteenth- and twentieth-century biology. They show that patterns of reasoning in theory construction can be obtained. The patterns may be useful in the future as well.

List of Works Cited

Burnet, F. M. (1957). "A Modification of Jerne's Theory of Antibody Production Using the Concept of Clonal Selection," *The Australian Journal of Science* 20:67–69.

Darden, Lindley (1980). "Theory Construction in Genetics," *Scientific Discovery: Case Studies*. T. Nickles (ed.) Dordrecht, Holland: Reidel. Pages 151–170.

———. (1982). "Artificial Intelligence and Philosophy of Science: Reasoning by Analogy in Theory Construction," *PSA, 1982*, v. 2. T. Nickles and P. Asquith (eds.). East Lansing, Mich.: Philosophy Science Association. Pages 147–165.

———, and Maull, Nancy. (1977). "Interfield Theories," *Philosophy of Science* 44:43–64.

Darwin, Charles. (1859). *On the Origin of Species*. Repr. Cambridge, Mass.: Harvard University Press, 1966.

Hanson, Norwood R. (1961). "Is There a Logic of Scientific Discovery?" *Current Issues in the Philosophy of Science.* H. Feigl and G. Maxwell, eds. New York: Holt, Rinehart and Winston. Repr. in *Readings in the Philosophy of Science.* R. Brody ed. Englewood Cliffs, N. J.: Prentice-Hall, 1970. Pages 620-633.

Hempel, Carl. (1966). *Philosophy of Natural Science.* Englewood Cliffs, N. J.: Prentice Hall.

Hesse, Mary. (1966). *Models and Analogies in Science.* Notre Dame, Ind.: University of Notre Dame Press.

Jerne, Niels K. (1955). "The Natural Selection Theory of Antibody Formation,"*Proceedings of the National Academy of Sciences* 41:849-857.

Kohn, David. (1980). "Theories to Work By: Rejected Theories, Reproduction and Darwin's Path to Natural Selection," *Studies in the History of Biology* 4:67-170.

Lamarck, J. B. (1809) *Zoological Philosophy.* Repr. New York: Hafner, 1963.

Langley, P., Bradshaw, G., and Simon H. (1980). "Rediscovering Chemistry with BACON.4," CIP Working Paper No. 423, Department of Psychology. Pittsburgh: Carnegie-Mellon University.

Popper, Karl. (1959). *The Logic of Scientific Discovery.* New York: Harper Torchbooks.

Steele, E. J. (1981) *Somatic Selection and Adaptive Evolution: On the Inheritance of Acquired Characters.* Chicago: University of Chicago Press.

What Is Revolutionary About the Copernican Revolution?

Werner Diederich

The rise of Copernicanism is not always called a "revolution." Robert S. Westman, for instance, speaks of the "Copernican Achievement" and Hans Blumenberg of the "Copernican Turn" (*kopernikanische Wende*). It should become clear, however, in the course of this paper, why I prefer to call the episode in question a revolution. The term *revolution* is, of course, mainly a political one. The French Revolution of 1789 has become something like the paradigm of a social or political revolution. It seems that our concept of revolution itself is only less than a hundred years older. Before that there was only the technical notion of *revolutio* as it appears in astronomy, for example in the title of Copernicus' book *De revolutionibus orbium coelestium.* This technical notion conceived of revolutions as cyclical processes, and it was in this sense that the term was used also in other fields well into the eighteenth century. Only then do we find a slow change toward the familiar, secular sense of the concept. Outside of the political domain, but still close to it, we find, for example, the notion of the Industrial Revolution and more recently that of the Scientific Revolution of the sixteenth and seventeenth centuries.[1] Thomas Kuhn, as we all know, generalized this idea in coining the common name *scientific revolution* in his 1962 essay, "The Structure of Scientific Revolutions." By way of irony THE (one, great) Scientific Revolution is something that evidently cannot count as a scientific revolution in Kuhn's sense—nor has it been claimed by Kuhn to be one.

Kuhn has been criticized often for his theory of scientific revolutions and for various reasons. One line of critique has been that there simply are not such episodes as scientific revolutions in Kuhn's sense, his examples notwithstanding. Such critics usually argue that the alleged scientific revolutions lack certain features characteristic for Kuhn's general notion, like incommensurability, crisis, and so forth. I, on the contrary, am convinced that there are scientific revolutions, though not quite in a Kuhnian sense. My critique of Kuhn will be that his notion of scientific revolutions does not adequately picture those episodes that are intuitively and legitimately called revolutionary.

A scientific revolution is regarded as the replacement of paradigms, or in a more recent terminology, of disciplinary matrices. I take *paradigm*, for short, in the broader sense of "disciplinary matrix" (Kuhn, *Postscript*). That is, a revolutionary process in science is considered to be a kind of *binary relation* between an old and a new paradigm.

What I want to show is that at least the Copernican Revolution does not display this linear pattern. There are good reasons to believe that the Copernican Revolution, as well as other so-called scientific revolutions, involves a change of "disciplinary structure," typically some branching and/or merging of scientific disciplines (and often of various sorts of non-scientific traditions). By *disciplinary structure* I mean the way science, at a given time, is organized as a system of various disciplines, their interconnections, degrees of dependence, hierarchical patterns between disciplines, relations to non-scientific traditions, and the like. The disciplinary structure of science changes over time, of course. Scientific revolutions, I suspect, may be characterized by especially drastic and comparably abrupt changes of the disciplinary structure.

Although Kuhn would not subsume the Scientific Revolution as a whole under his general notion of scientific revolutions, this is certainly not so far that part of the Scientific Revolution that we call the Copernican Revolution. Kuhn himself has written a book with that title; and although this book appeared five years before *The Structure of Scientific Revolutions*, Kuhn makes it quite clear in both books that he regards the Copernican Revolution as an example of a scientific revolution, and indeed a paradigmatic one.

Let me draw some main lines of the Copernican Revolution as a background for later consideration.

I regard the Copernican Revolution as a process taking roughly 150 years, namely the years between Copernicus' *De Revolutionibus*, printed in 1543 (but written decades earlier) and Newton's *Principia*, published in 1687. The main names to mention between Copernicus and Newton are, of course, Kepler and Galileo, who were roughly contemporary. While Copernicus confined himself almost totally to mathematical astronomy—and stood in the Ptolemaic tradition for that reason—Kepler and Galileo tried to establish a physical cosmology based on Copernican astronomy. Kepler's work, besides being well known for his breakthrough in planetary kinematics, is also remarkable in attempting a physical explanation of the planetary system; he tried this by postulating magnetic forces between the sun and the planets (instead of a special *anima motrix*, attributed to the sun by himself earlier). While Kepler thus in a way applied terrestrial physics to the heavens, Galileo worked the other way round: he took the even, circular motions of the skies as a paradigm for terrestrial natural motions as well. In this way, Galileo took an important step towards the principle of inertia. Finally, Newton corrected, emended, and combined Kepler's planetary laws and Galileo's physics in his unifying theory of general mechanics and universal gravitation. Generally speaking, the Copernican Revolution brought about a unification of earth and heavens that could not have been conceived of in the Aristotelian world picture.

We have now the following rough account of the Copernican Revolution. If there was any single discipline in which the Copernican Revolution took place, it was only a discipline coming into being, namely physical astronomy (or astronomy in the modern sense), which grew out of the loose connection, woven mainly by Kepler and Galileo, of the two previously independent disciplines—mathematical astronomy and natural philosophy. Each of these two fields had to have its own break with tradition beforehand: astronomy in the work of Copernicus, and natural philosophy in the work of Galileo.

We have seen that the Copernican Revolution is by no means a revolution of astronomy alone, but also one of physics. We should realize, however, that it might not be feasible to stop here. For a full understanding of the Copernican Revolution we should go beyond physics and also have a look at other fields of natural science, as well as at the broad philosophical background, and even include theological speculations. Finally, the revolutionary character of the Copernican Revolution can hardly be estimated without a parallel account of the social and economic developments of the period; but I shall confine myself to intellectual history.

With regard to other fields of natural science, I would draw your attention to the development of *anatomy* in the sixteenth and seventeenth centuries. It looks as if there is a striking parallel between the detection of the circulation of the blood and the development of Copernican astronomy, that is, in Renaissance terms, of the revolutions of micro- and macrocosm. If you look for the years of appearance of the main works, you find both revolutions starting in 1543, with Vesalius' *De humani corporis fabrica* and Copernicus' *De revolutionibus orbium coelestium*, respectively. Again, both revolutions culminate roughly at the same time in Harvey's *De motu cordis* (1628) and Kepler's *Harmonice mundi* (1619).

I do not claim that there is any close interaction between the two revolutions. Certainly there is some support from astronomy to physiology. To be more precise: heliocentric cosmology together with the still viable microcosm/macrocosm analogy helped to gain acceptance for Harvey's theory as against the Aristotelian-Galenic tradition (which does not contradict the fact that Harvey himself was an ardent admirer of Aristotle and Galen). Thus Robert Fludd, contemporary and friend of Harvey, had already conceived of a circulation of the blood for mystical reasons in 1623; he argued with the microcosm-macrocosm analogy, as did Harvey himself:

> The heart, consequently, is the beginning of life; the sun of the microcosm, even as the sun in his turn might well be designated the heart of the world; for it is the heart by whose virtue and pulse the blood is moved, perfected, made apt to nourish, and is preserved from corruption and coagulation; it is the household divinity which, discharging its function, nourishes, cherishes, quickens the whole body, and is indeed the foundation of life, the source of all action. (85)

It seems that the first support for Harvey's thesis was more on this line of thought rather than by his experimental proofs. I know of no direct reference to the circulation of the blood in the astronomical literature, however. But it very much looks like there is at least a certain common source of ideas that helped both revolutions to succeed. One idea is that of revolution itself, this time meaning the revolution of the blood or the earth, respectively. The renewal of the blood and the whole process of life are explained by Harvey's revolutions of the blood, as are the most spectacular celestial phenomena by the diurnal and annual revolutions of the earth. Another idea is that of the central organ reigning over the respective motions, namely the heart pushing the blood all over the body and thereby vivifying all its parts, and the sun causing the planets' revolutions and supplying them with light and warmth necessary for all life processes.

The role of the sun takes me to the next point I want to make, namely that the Copernican Revolution is hardly understandable without considering the support from Renaissance Platonism.[2] It is more than evident that Johannes Kepler drew a lot of ideas and energy from this background; his writing is full of hymns to the sun as a support for heliocentricity. Less well known are a few passages in this direction in the writing of Copernicus himself (who was quite contrary to Kepler with respect to style of writing). For example, towards the end of the exposition of his system, in the tenth chapter of the first book of his *De revolutionibus,* Copernicus writes

> In the middle of all sits Sun enthroned. For who would place this luminary in this most beautiful temple in any better position from which he can illuminate the whole at once? He is rightly called the

> Lamp, the Mind, the Ruler of the Universe; Hermes Trismegistus names him the Visible God, Sophocles' Electra calls him the All-seeing. So the sun sits as upon a royal throne ruling his children the planets which circle round him. The Earth has the Moon at her service. As Aristotle says, in his *On Animals*, the Moon has the closest relationship with the Earth. Meanwhile the Earth conceives by the Sun, and becomes pregnant with an annual rebirth.
>
> (Kuhn, *Copernican Revolution* 179)[3]

This passage suggests that Copernicus' motivation for heliocentricity is at least partly to be found in Renaissance Platonism. This is not all too surprising, since it is more than probable that Copernicus got in touch with such ideas during his student years in Italy, where the respective traditions were well known, for example, through the writing and editions of Marsilio Ficino in the second half of the fifteenth century. Thus we find in Ficino's *Liber de Sole* (1576) this hymn to the sun:

> Nothing reveals the nature of the Good [which is God] more fully than the light [of the sun]. First, light is the most brilliant and clearest of sensible objects. Second, there is nothing which spreads out so easily, broadly, or rapidly as light. Third, like a caress, it penetrates all things harmlessly and most gently. Fourth, the heat which accompanies it fosters and nourishes all things and is the universal generator and mover. . . . Similarly the Good is itself spread everywhere, and it soothes and entices all things. It does not work by compulsion, but through the love which accompanies it, like heat [which accompanies light]. This love allures all objects so that they freely embrace the Good. . . . Perhaps light is itself the celestial spirit's sense of sight, or its act of seeing, operating from a distance, linking all things to heaven, yet never leaving heaven nor mixing with external things. . . . Just look at the skies, I pray out, citizens of heavenly fatherland. . . . The sun can signify God himself to you, and who shall dare to say the sun is false.
>
> (Kuhn, *Copernican Revolution* 130)

It is by no means clear, however, how far the Neoplatonic influence on Copernicus goes. There is little evidence in his writing for the source of his ideas. A notable exception is the following out of the prefatory address to Pope Paul III, with which he opens his *De revolutionibus:*

> I pondered long upon this uncertainty of mathematical tradition in establishing the motions of the system of the spheres. At last I began to chafe that philosophers could by no means agree on any

> one certain theory of the mechanism of the Universe, wrought for us by a supremely good and orderly Creator, though in other respects they investigated with meticulous care the minutest points relating to its circles.
>
> (Kuhn, *Copernican Revolution* 141)

The "mechanism of the Universe" to which Copernicus refers here is, in the Latin original, the *machina mundi, qui propter nos ab optimo et regularissimo omnium opifice conditus est.*[4] Hans Blumenberg stresses the phrase *propter nos* and refers to the expressed principle as Copernicus' "teleological world-formula" (*teleologische Weltformel*) (51ff). This is meant in a theoretical aspect: it is an epistemological teleology that is at stake. Copernicus believes that the world is made in such a way that it is understandable for us. Therefore, it is a *scandalon* for Copernicus that there is so much uncertainty about "the principal thing—namely the shape of the Universe and the unchangeable symmetry of its parts" (Kuhn, *Copernican Revolution* 139).

Now, as we know, the Copernican achievement did not concern mathematicians and philosophers alone. Outside the comparatively small community of astronomers it was, of course, more the metaphor of Copernicus' worldview that was relevant to its reception. The fact that quite contrary reactions took place mirrors the ambivalence of the new metaphor. On the one hand, it was taken as a triumph of mankind that the earth was ranking now as a star, participating in the motions of the heavens; this reaction is quite obvious in Galileo.[5] On the other hand, the loss of the central position was regarded as a loss of dignity; the universe no longer centers around mankind and its place. Both kinds of reaction were to continue up to the nineteenth century at least; for Goethe, the Copernican Revolution and its consequences are a gain, for Nietzsche a loss for mankind (Blumenberg 122).

It is well known that there was considerable resistance against Copernicanism in the Church; first, by the way, more on the Protestant side, later on more and longer lasting grounds on the Catholic side. It is important to note that there had not been any explicit dogma of geocentricity before the Copernican Revolution (Blumenberg 131). In Aristotelianism, the central position of the earth had no metaphysical dignity, but only a physical: the element earth, as the heaviest one, is to be found in the middle of the world. It was only later that the church came to insist so stubbornly on the central position of the earth. Cusanus in the fifteenth century with his rather heterodox cosmological ideas had not run into trouble at all. Luther and Melanchthon, although opposed to Copernicus' ideas, did not care very much about these matters (Blumenberg 104). Still, Bellarmin, who was to become

Galileo's main opponent in the Church, rejected Copernicanism only rather reluctantly. The circumstances under which geocentricity was made into a Christian dogma are understandable only if one takes into account the social aspects of the Copernican metaphor. As I said, however, I am not going into these aspects in this paper.

To summarize our account of the Copernican Revolution, let me recall that we first observed that this revolution cannot be understood as a process within astronomy alone, but only as a process that also involves the development of physics. But this emerging of modern physics is not just a byproduct of the evolution of modern cosmology, but an originally independent development that only became more and more intertwined with that of astronomy. Hence, modern cosmology has at least these two, originally quite independent, roots; that is, the Copernican Revolution cannot be understood as to bear a *linear structure* in the way Kuhn conceives of scientific revolutions.

The situation is, in fact, even more complicated. There are parallel developments in other disciplines, like physiology, which it is necessary to account for if we aim at a full understanding of the Copernican Revolution; the background of Renaissance Platonism seems to be a link for the observed analogies.

Even more important for an adequate account of the revolutionary character of the rise of Copernicanism is the latter's metaphorical rule. What is at stake is not only a new model for the universe, but a new epistemology. Copernicanism means a regained confidence in human ability to comprehend the world, a confidence characteristic of the Scientific Revolution more generally.

We have seen that the Copernican Revolution is a rather complex process at the end of which a new discipline has evolved: modern (Newtonian) cosmology. Although we can point to a fairly definite result of the Copernican Revolution, its origins are far less definite, manyfold, and only partly scientific: at least Renaissance Platonism, Copernicus' reversal of Ptolemean astronomy, and Galilean mechanics must be named.

This structure of the Copernican Revolution is also typical for the Scientific Revolution in general, that is for the evolution of modern science in the sixteenth and seventeenth centuries. There is no comparable complex of scientific theories, aims, and methods at the outset of the Scientific Revolution. In fact, compared with science as it results about 1700, there is hardly any science in 1500, besides the few classical disciplines of astronomy and medicine, and so on. The whole complex of so-called Baconian Sciences with their origins in craftsmanship and magic (e.g., chemistry originating in alchemy) came up only in the meantime.

Is there anything that can *structurally* characterize the Scientific Revolution or at least the Copernican Revolution in the Kuhnian sense? I suspect that if this question makes any sense at all, we can point only to one feature in this respect: the non-linearity of the Scientific Revolution. I propose to take as a structural characteristic, therefore, a feature that does *not* fit into the Kuhnian pattern.

What I have called *non-linearity* may not even be confined to this particular revolutionary epoch. It may be characteristic also of other processes that Kuhn calls revolutions. One reason why Kuhn's pattern does not apply to the Scientific Revolution, in fact, is that his concept was drawn from the later history of science. For these later periods where science is institutionalized and independent and where scientists are more self-confident, it makes more sense to characterize science by inner-scientific processes and to conceive of changes that affect scientific communities and nothing else. Kuhn's notion of scientific revolutions is rather scientistic and applying it to pre-modern cultural revolutions can result in nothing other than Whig history.

The Scientific Revolution is not so much a revolution of science—that is, a process occurring within science, where a new sort of science replaces an old one—but the emergence of science itself. Of course, there had been science before, but only a limited kind, scarcely mathematized, hardly relying on objective observation and experimentation, and practically and socially unimportant. All this changed drastically and for various reasons, both internal and external.

Yet some traits of the Scientific Revolution do resemble Kuhn's conception. During a revolution, for example, a whole new way to conceive of reality is brought up, and a new world view installed. This is exactly what happened during the Scientific Revolution, and in a most radical way. In fact, it seems that for a lot of Kuhn's readers, large scale revolutions such as those happening in the sixteenth and seventeenth centuries were paradigmatic examples of what Kuhn was talking about. But Kuhn himself tended to stress changes in science that bear the structure of scientific revolutions but that may affect only a few scientists (so-called mini-revolutions).[6]

One may wonder whether my proposal to characterize scientific revolutions by changes of the disciplinary structure really disagrees with Kuhn's understanding. The tension between my proposal and his account of the Copernican Revolution, on the one hand, and his *The Structure of Scientific Revolutions*, on the other, might be somewhat superficial. Indeed, two recent papers by Kuhn show that my ideas seem not too far away from his.

In a booklet, *Was sind wissenschaftliche Revolutionen?* and in his contribution *Rationality and Theory Choice* to a symposium on C. G.

Hempel's philosophy of science, Kuhn develops a concept of *local holism*, as he calls it in the later paper. The notion is preferably exemplified by the way the key concepts of Newtonian mechanics, namely mass *m* and force *f* depend on each other via the fundamental law of that discipline, namely Newton's second law $f=m \,.\, a$—*a* being the acceleration of a body (or a mass point) of mass *m* effected by a force *f* on that body. Kuhn notices that the terms *mass* and *force* are not learned seprarately, but only together by the way they function in applications of Newton's second law.

Perhaps Kuhn's local holism with regard to Newtonian Mechanics is best understood by way of comparison with respective traits of Aristotelian physics. In the earlier paper, Kuhn gives a lively and rather convincing account of the difficulties that somebody trained in Newtonian physics has to overcome in order to understand Aristotelean physics. The way that seems natural at the outset—to ask what Aristotle has contributed to the theory of motions as it appears in Newton—proves totally inadequate as soon as one realizes that all the key terms (for example the term *motion*) have different meanings for Aristotle, and that these meanings are interdependent analogously to the way mass and force are interdependent in Newton. Hence, one cannot directly compare Aristotle's theory with Newton's without a new language rooted in a quite different *Weltbild*. After providing two more examples (from Volta's theory of electricity and from Planck's early quantum physics), Kuhn characterizes revolutions with respect to the observed holism: revolutions are holistic in the sense that they change the meanings of some fundamental terms interdependently; they alter that part of knowledge that is intrinsic to language itself.

In the second paper, Kuhn transforms the reported holism to the higher level of science itself as compared with other cultural activities such as art. We cannot understand science in isolation without incidentally understanding other, comparable activities.

The connection between Kuhn's thought and my thesis concerning scientific revolutions as disciplinary changes is as follows. Changes in disciplinary structure are understandable only against a background of a holism of the Kuhnian sort, but a holism on a "medium" level between that of scientific terms such as *mass* and *force* and that of science in general. This medium level regards the conceptions of scientific disciplines such as astronomy, physics, chemistry, and so forth (including in some contexts also a borderline discipline such as astrology). A revolution in one discipline must be considered in light of what is happening in the neighboring disciplines since the others are changing interdependently. For instance, the role and understanding of the disciplines of mathematics, astronomy, and physics changed drastically during the Copernican Revolution. To put it in Kuhnian terms, you learn what mathematics, astronomy, and physics mean only *together* by incidentally learning how these disciplines relate. This holism of disciplines accounts for the widespread resistance to revolutions that seem at first glance to affect only one discipline.

Kuhn's local holism accords generally with my thesis of revolution as disciplinary change. There are, however, two differences in focus. Kuhn considers the holism of key terms of scientific theories, while I consider the interdependencies of the (medium-level) meta-scientific conceptions of scientific disciplines. The other point of difference is Kuhn's linguistic manner of presenting his holism, stressing the peculiarities of learning the meanings (and changes of meaning), while I prefer to express the holism structurally.

I do not claim that my account—or any account—gives in itself an adequate understanding of the structure of scientific revolutions. For a fuller understanding, one has to say something about how a revolution comes about. I do not pretend to answer this question, but only to outline a model that may serve as a guide to ask the right questions for each revolution to be studied.

The model that I want to propose is what I call the *magnet model* for scientific revolutions. As we know from physics, a magnet is composed of a number of so-called elementary magnets. If these (or most of them) are oriented in the same direction, there is the macroscopic effect of an an-isotropic piece of matter with certain poles localized somewhere beneath the surface. If this magnet is put into a magnetic field with a different direction, the magnet will, within a certain time, be reorientated to the outer magnetic field. This happens by a succession of switches of the elementary magnets, or of groups of them, into the new direction. When all or most of the elementary magnets are re-orientated, the magnet has changed its direction.

To decipher this model of a scientific revolution one may interpret the elementary magnets as pieces of a theory of, more broadly speaking, a paradigm in Kuhn's sense, or, alternatively, as a group of scientists participating in a revolution. It does not really matter whether you choose an epistemological or sociological interpretation of the model. What matters are two things that the model is supposed to express:

(1) That a revolution comes about by a number of small changes, one after the other, taking a certain time. During this time interval there is no general orientation. It is an unstable phase, a transition to a still unknown new state.

(2) That the perspectives and motives of the individuals involved may be very heterogenous. Each small change takes place for certain local reasons, for example, in pursuing coherence of certain parts of a theory

that has begun to change already. The outer magnetic field of the picture may not be—and perhaps typically is not—visible to those involved. Hence the revolutionary nature of the process may be misunderstood or not understood at all by the participants; it is the post facto category of the historian, who sees the outer magnetic field in action.

A case in question is again the Copernican Revolution, at least in the early phase. A few decades after Copernicus' death, there was little consciousness about the revolutionary impact of Copernicus' innovations among astronomers (Rheticus being one notable exception). As Westman has shown,[7] the reception of Copernicus' ideas was only partial even among those astronomers who were concerned with Copernicus' theory at all. Only piece by piece, and scientist by scientist, the revolution finally came about.

Interestingly, heliocentrism was not a main issue of early Copernicanism, but certain computational advantages were. I should add that geocentrism was not a main issue for astronomers of that time. It was more of an unquestioned background assumption. Only slowly, while Copernicus' theory became more and more accepted (*despite* his heliocentrism), did geocentrism become a debatable scientific hypothesis. Only by the emergence of an alternative that eventually was taken seriously did the old paradigm become visible.

Notes

Preliminary studies to this paper were supported by a senior visitor followship of the Center for Philosophy of Science at the University of Pittsburgh.

[1] The phrase is A. Koyré's (1943), cf. V. L. Bullough (ed.), *The Scientific Revolution*, Huntington, N. Y.: Krieger, 1978, 1.

[2] For the present purpose I take this in rather a broad sense to include not only Neoplatonism as renewed during the Renaissance, mainly in the fifteenth century, but also the Renaissance absorption of Pythagoreanism, Hermeticism, and related currents.

[3] Kuhn takes over, with minor changes, the translation of the Royal Astronomical Society, 1947, by F. Dobson and S. Brodetsky.

[4] Latin/German Akademie edition, ed. Georg Klaus, Berlin 1959, 10.

[5] Cf. for example his *Sidereus Nuncius* (1610).

[6] In the first edition of *The Structure of Scientific Revolutions*, Kuhn regarded the great revolutions connected with the names of Newton, Lavoisier, and Einstein as paradigmatic cases. See his *Postscript* to the second edition for considerable changes in this respect.

"The Melanchthon Circle, Rheticus and the Wittenberg Interpretation of the Copernican Theory," *Isis* 66 (1975), 165ff.

List of Works Cited

Blumenberg, Hans. *Die Kopernikanische Wende.* Frankfurt: Suhrkamp, 1965.

Harvey, William. *The Circulation of the Blood and Other Writings.* London, 1952.

Kuhn, Thomas. "Rationality and Theory Choice." *Journal of Philosophy* (80) 1983: 563-570.

———. *The Structure of Scientific Revolutions.* 2nd. ed. Chicago: University of Chicago Press, 1970.

———. Werner Heisenberg Lecture, Munich, February 1981, published by the Carl Friedrich von Siemens Stiftung ("Themen" 34).

Intimations of Rationality: Construction of Theories in the Physical Sciences

H. R. Post

"All origins are obscure." We cannot hope to explain pioneering work in science completely. But we may say something about motivation and method.

Aim and method are, of course, related, and either is influenced both by subjective and objective factors. The atomist aims to explain in terms of discrete units and is likely to follow Kronecker ("God made the integers"). Others consider the continuum "deeper" than the natural numbers, assign a continuous structure to space and time, and use the formalism of the differential calculus (see Shrödinger's *Antrittsvorlesung*). The resulting theory is, of course, judged not only by the aesthetic sense of the author, but by certain inter-subjective standards.

The first step in scientific work is the mastering of a net of connections, each of which is separately known at some theoretic level. This mastery is akin to the art of memory and may involve a coding of the information into a more compact form. This may result in a new, more powerful theory. I remember my tutor proudly announcing that the next edition of his authoritative textbook would be "thinner than ever; we are making progress." Here, as in other cases, pedagogy provides a model of progressive understanding. Successive textbooks usually document to the historian of science progress in understanding and even progressive (although not always explicitly acknowledged) change in the theory. An outstanding example of pioneering science in an educational context is the appearance of a periodic system of the chemical elements (without discussion) in an introductory textbook for agricultural students in the mid-nineteenth century.

The next step is the identification of a problem.[1] Some problems may be classified in terms of inter-subjectively intelligible criteria of science. The requirement of logical consistency[2] is an obvious criterion of constraint on theory-building. In a more general sense, scientists aim at *coherence* ranging from the search for theories unifying existing ones to taking the negative heuristic hint provided by the existence of a paradox in a given theory.

Examples of mathematical inconsistencies in a theory include the infinities of quantum field theory that lead to "renormalisation" programmes but suggest more radical new theories. In the application of classical statistical mechanics to black-body radiation, the "ultraviolet catastrophe" (of energy contribution increasing towards infinity with shorter wave-lengths), a strict consequence of classical theory, should have been a strong guide to quantum theory. Boltzmann claimed that the greatest success of his statistical mechanics was the removal of the reversible mechanics-irreversible thermodynamics paradox. Such paradoxes, apparent formal contradictions, are useful hints of a higher and wider system in which these contradictions are eliminated. Progress in physics is frequently analogous to the steps from paradox (the liar) via incompleteness (Gödel) to truth (at a meta-level) in logic: "The knowledge of privation, like all other knowledge, in the end is positive. You cannot speak of the absent and lacking unless you assume some field and some presence elsewhere" (Bradley 457).

The most revolutionary example of a flaw leading to a new fundamental physics is the transition from classical physics to special relativity. Classical physics consisted of two disparate parts: Newtonian (Hamiltonian) mechanics on the one hand, and Maxwell's electromagnetic theory (including optics) on the other. Every physicist hoped for, and many worked towards, a unification of these two parts—most attempted a reduction of electromagnetism to mechanics, following Maxwell. Now Newtonian mechanics is Galileo-invariant. On the other hand, Maxwell's theory is not. It is invariant under a different transformation, the so-called Lorentz-transformation. It is obviously impossible to unify two theories with different invariance properties, since unification in one coordinate system would be destroyed in another. One or both theories had to be altered. Einstein describes how he was led to his theory of relativity by a thought experiment showing that a Galileo transformation on a light wave would falsify Maxwell's theory (53). Einstein was so imbued with Maxwell's theory that he was led to reject Galileo-invariance. He then reformulated mechanics in a Lorentz-invariant way (special theory of relativity).

This brings us to another influential criterion in science: *symmetry* (and the related principles of conservation). In the last resort, it is the scientist who chooses the symmetry of his new theory. But he is faced with the task of explaining the symmetry exhibited by previously successful theories and any breakdown of that symmetry in special experiments. The abandonment of left-right symmetry is perhaps the most revolutionary break-through in contemporary physics. Though the lack of cylindrical symmetry in certain experiments with beams of particles might rationally have been detected within the theoretic framework in which these experiments were conducted, no conclusive test of cylindrical symmetry was in fact carried out until Lee and Yang suggested non-conservation of parity (to account for a flaw in elementary particle theory). New symmetries were introduced later. The role of symmetry was indeed overstated by Einstein who mistakenly held that the requirement of co-variance was sufficient to lead to specific theories. He had to modify this statement, substituting the requirement of "maximum simplicity in their covariant formulation."

In their choice of problem we may again identify characteristic preferences in individual scientists. We have examples of scientists battling with a certain class of problem throughout their lives[3], and scientists who show a similar faith in a particular type of solution. Boltzmann is an example of both: his life-long problem was to unite thermodynamics and mechanics, and he had a quasi-religious commitment to atomism. The conflicting solutions claimed by Newton and Laplace to the several-body problem in astronomy may perhaps be attributed to the different religious views they held.[4]

When the scientist has identified his problem there now intervenes the private world of thought and the unconscious. Hadamar's *Psychology of Invention in the Mathematical Field* is very relevant here. One of the messages of his book is the importance of non-conscious processes in scientific work. Moreover, these unconscious processes may reveal rationality.[5] I have experienced myself the phenomenon of initial failure at the conscious level to connect theories that subconsciously had been constructed jointly. Unlike the great mathematician Poincaré, I had only two scientific problems at that period: to study the properties of translation-invariant functions, and to find the necessary and sufficient condition that a certain solution of the many-body problem applied. These problem areas were not consciously connected in my mind. Then I suddenly realised that translation-invariance was the condition looked for. Again, as in the case of Poincaré, it was at a moment when I could not check this, but I had absolute confidence that this was true, that I would not forget till I had leisure to check—and this was indeed the case. The unconscious, far from playing randomised Monte-Carlo computer games, can supply deeper connections.

One of the bridges from the private world of thought back to the articulate world of science is realisation through *models*. This makes vague ideas more definite and makes criticism possible. It is a separate question how seriously a particular model is to be taken. It may be merely the expression of a hoped-for vague analogy between one's idea and a known subject, it may be the formal realisation of a theory, or it may even be an enriched model with features suggestive of further enlarged theories. The history of chemistry has many instances of the ambivalent use of models. Kekulé, one of the fathers of structural formulae, was rather sceptical of van't Hoff's interpretation in three-dimensional space. Dreams should not be taken too far.[6]

It is frequently the case that the old theory contains the seed of the new theory, not as a flaw but by way of a suggested model. We should distinguish between the strict logical consequences of a theory, its dividends, and such further suggestion, which might be called a bonus. Chemical formulae were only gradually accepted as actually denoting the configuration of atoms in space. Similarly, crystallographers had used regular arrays of units as models of crystals for a century before physicists took this model sufficiently seriously to identify the units with physical atoms (Laue). Taking seriously a model suggested by a theory is often pragmatically successful. This is only one form of the general phenomenon that scientists "builded better than they knew." Planck introduced light quanta ad hoc to account for the spectral distribution of radiation; later, Einstein suggested that these photons also showed up in the process of emission and absorption, predicting the photochemical and photo-electric effects. Emerson's poem applies to scientific theories as well as to abbeys. The criterion applies to the invention of what Einstein called "constructive theories." The programme of atomism is an apotheosis of a constructive theory (Post "Atomism," 1900). A similar procedure consists in extending interpretation to hitherto uninterpreted terms of a theory. Theoreticians are carried along by their momentum within mathematics in a definite direction. In the heuristic situation, scientists do not just try to save the phenomona—they also try to save the laws, and they accept refutation by the calculus adopted. It is this balance of theory and experiment that results in definite guidelines. This balance is again a subjective matter: "One should keep the need for a sound mathematical basis dominating one's search for a new theory. Any physical or philosophical idea that one has must be adjusted to fit the mathematics. Not the other way round. . . . The need for putting the mathematics first comes from its more rigid nature. One can tinker with one's physical or philosophical ideas to adapt them to fit the mathematics. But the mathematics cannot be tinkered with. It is subject to completely rigid rules and is harshly restricted by strict logic" This statement, made by Dirac, of all people, in his last years, may be balanced against the much earlier statement by Einstein: "It does seem to me that you greatly overestimate the value of formal considerations. These are very valuable when the task is to find a final formulation for a truth already found—but they fail almost invariably as heuristic considerations" (translation of a postcard to F. Klein).

In this last stage, a fourth factor in theory-building enters that has already been mentioned: *simplicity*. Simplicity in scientific theories can be defined (see Popper's *The Logic of Scientific Discovery*). The known universe is then found to be simple in two respects: it is describable by simple laws at least to some extent, and these laws contain suggestions how they may be fitted into into a wider context of still simpler laws—pragmatic simplicity (Post, "Simplicity in Scientific Theories"). Significant simplification is already possible on the purely linguistic level, and there is an essential connection between this linguistic simplicity and semantic simplicity. The procedure of simplification on the linguistic level is a system of coding. Starting with a basis-language preferred on operational grounds, an inverse measure of linguistic simplicity is provided by the length of the coded message stating the theory. The rule: "A good theory is a good mnemonic" may perhaps be seen to be founded on an isomorphism between theory-construction and a certain type of memorising (Oldfield 14).

The claim of this paper, then, is that even the most revolutionary creations follow some guidelines, even in the critical middle stage between the definition of the problem-situation and the first tentative solution. The sequence of steps may be described as starting with the detection of a flaw in the existing theory and taking this flaw as a "footprint" from which to construct the new theory while attempting to retain as many confirmed invariance principles as possible. The choice of new theory may be guided further by tentatively giving an interpretation to hitherto uninterpreted parts of the formalism of the old theory, or by taking models seriously. An important constraint is the correspondence principle.[7] Roughly speaking, this is the requirement that any acceptable new theory L should account for the success of its predecessor S by degenerating into that theory under those conditions under which S has been well confirmed by tests. The General Correspondence Principle not only demands agreement of the L-theory with the S-theory in singular statements relating to certain events, but it claims that any L-theory will in fact embody a good deal of the (lower) theoretical structure of the S-theory. Only in this way is the success of S *explained*. Among the candidates for the new theory, the simplest is chosen. These guidelines are very general and vague and allow enormous scope for individual initiative and choice. They are far from sufficient, but they may be necessary, for success in science. Mastery shows in constraint in science as in art.

The individual scientist, the atom of the history of science, like the chemical atom, is not quite invariant. His character, his characteristic spectrum of possible states, is normally invariant. But he may change from one state within this spectrum to another under collision with another scientist, in the alternating field of prevailing opinion, or by coming up against the hard wall of empirical facts. He may—but he need not. His threshold for transition from one internal state to another may be too high for him to be influenced by such external disturbances. Nor is it necessarily a good thing to have a low threshold. If the atomists of the nineteenth century had not persisted in their prejudices in spite of the necessity to introduce ad hoc fractional atoms or polyatomic molecules of elements, the progress of science would have been retarded. As Polyanyi points out, "There is a residue of personal judgement required in deciding—as the scientists eventually must—what weight to attach to any particular set of evidence in regard to the validity of a particular proposition.

We might perhaps raise the converse question of how it is that many different predilections lead to success. Perhaps it is because the world is so full of a number of things that any template representing an individual "mind-set" will fit some aspect of the world somewhere. On the other hand, there does seem to be convergence in the case of any *specific* problem. As Einstein says, "It is similar to a man engaged in solving a well-designed word puzzle. He may, it's true, propose any word as the solution; but there is only *one* word which really solves the puzzle in all its forms. . . . The historical development has shown that among the imaginable theoretical constructions there is invariably one that proves to be unquestionably superior to all others." The progressive convergence towards that ideal solution is spelled out by the correspondence principle, which demands that any future theory has to explain the success of past theories. Subject to this constraint, any prejudice is better than none.

Notes

[1] This step may be greater than might appear to an outsider. The professor who replied to a student who asked him for a problem, "If I had a problem I would solve it myself," was making a serious point.

[2] Non-scientists may not be aware of the extent to which this principle is honoured in the breach by quantum mechanics. The famous Einstein-Podolsky-Rosen paradox is only a symptom of a deeper inconsistency in the recipies of quantum mechanics: "Measurement" remains undefined in order to avoid clashes with quantum mechanics principles.

[3] See the autobiographical articles by Lamb and Schwinger in *The Birth of Particle Physics* and Born's charming account of searching for "his" field in *My Life*.

[4] The heroes of science include those who went against their ideology in light of evidence, such as Planck.

[5]This may be contrasted with the following model of problem solving: Random ideas are thrown up against a filter that only passes those meeting certain requirements. A materialist-evolutionist view suggests further that the ideas thrown up are already shaped by ecological history to be in a set of more or less suitable ideas.

[6]Kekulé's instruction to his colleagues was "Learn to dream."

[7]See Post, "Correspondence, Invariance and Heuristics," and N. Koertge, "Inter-Theoretic Criticism and the Growth of Science," *Boston Studies in the Philosophy of Science*, VIII, eds. Buck and Cohen (1972).

List of Works Cited

Bradly, H. R. *Appearance and Reality*. Oxford, 1962.

Einstein, Albert. *Albert Einstein: Philosopher-Scientist*. P. A. Schilp, ed. New York, 1951.

Oldfield, R. C. "Memory Mechanisms and the Theory of Schemata." *British Journal of Psychology* 45 (1954).

Post, H. R. "Atomism 1900." *Physics Education* 3 (1986).

———. "Correspondence, Invariance and Heuristics: In Praise of Conservative Induction." *Studies in History and Philosophy of Science* 2(1971).

———. "Simplicity in Scientific Theories." *British Journal of the Philosophy of Science* 11(1960).

Panel Topic

Neurological and Psychological Views

Creativity and the Behavioral Sciences

Ronald D. Gordon

Behavioral scientists tend to specialize in what De Bono (1968) has termed "vertical thinking." Vertical thinking is logical, analytical, linear, precise, measured, and critical. It categorizes, gives detailed labels, and dissects. It is the most respectable type of thinking within most sciences. Lateral thinking proceeds differently. Keats' "willing suspension of disbelief" prevails, and eureka moments of "ah-ha!" are sought through extra-logical means. Vertical thinking is wooden blocks of ideas stacked atop the other, each fitting those others as neatly as possible. Lateral thinking is these same blocks cast deliberately upon the floor, each to assume a range of more spontaneous places in relation to the others, all of this to be explored for interesting and hopefully useful arrangement.

De Bono states flatly that "new ideas depend on lateral thinking, for vertical thinking has inbuilt limitations which make it much less effective for this purpose. These limitations of vertical thinking cannot be set aside, for they are its very advantages, looked at from a different point of view"(16). Vertical and lateral thinking styles, then, are not to be seen as incompatible but as complementary. When verification is needed, vertical thinking can serve the thinker well. When discovery of question and method is needed, vertical thinking benefits from being supplemented by lateral thinking.

In spite of the complementarity possible between vertical and lateral thinking styles, it seems that mbst behavioral scientists proceed fairly independent of much lateral thinking. As a result, there are major ways in which the behavioral sciences suffer from a lack of creativity. One suggestion for possible change will be woven into this discussion.

Karl Weick holds an endowed chair in organizational behavior at Cornell. He is also editor of *Administrative Science Quarterly*. In 1982, Weick commented that "most social science research is a demonstration of facts we aready know to be true, but about which we feel hesitant to make assertions given professional norms about the correct form of truth. In the interest of acceptability, we gild the inquiry as if it were detached discovery and as if disconfirmation were the goal" (441). One of this country's most distinguished social psychologists, William McGuire (1973), has suggested that this tendency has its antecedents in the graduate training of behavioral scientists, where "we try to train people to be good enough stage managers so they can create in the laboratory simulations of realities in which the obvious correctness of our hypothesis can be demonstrated" (449). McGuire's observation reminds me of a study in one of the communication journals of what were termed "Friendly Insult Greetings (FIGS)." It was found that the greeting "Hi, dummy" or "Hi, stupid" is acceptable at the "friend stage" of interpersonal relationship, but it is not well received prior to that stage. To account for this finding, the concepts that were advanced included "rules-system," "devious messages," "pragmatic vs. semantic levels of meaning," "the cooperative principle," "level of uncertainty," "normative behavior expectancy," "relational level," and "relationship development." The general conclusion was that "Friendly Insult Greetings (FIGS) are perceived as non-normative risky behaviors within the cooperative principle as demands which are not considered mutually relevant until the relational stage is reached" (Powers and Glenn 1979, 273).

It was Immanuel Kant (Dubos 1965) who astutely noted that "To yield to every whim of curiosity, and to allow our passion for inquiry to be restrained by nothing but the limits of our ability, this shows an eagerness of mind not unbecoming to scholarship. But it is wisdom that has the merit of selecting from among the innumerable problems which present themselves, those whose solution is important to mankind" (265).

Creativity in the selection of research questions, for this writer, would entail the asking of questions whose answers could make a difference to societal and world well-being (Gordon 1982, 2). In the context of the present-day social sciences, this would indeed stand out as a creative act. A definitive set of criteria for judging creative acts and products still does not exist. In most discussions of what constitutes creativity, however, the criterion of originality is included, defined as "statistical infrequency" (Besemer and Treffinger 1981, 163). When evaluating an art object, for instance, one guiding question would be how often in a gallery one is likely to see a work like the one being considered. In other words, a creative product is in part one that is infrequently seen in a universe of products made by people with similar experience and training. Extremely little is known about creative problem-finding. Creative problem-finding is generally not taught at any educational level. Instead, attention is given to the solution of presented problems; and this method produces "graduate students who are well enough equipped to execute a dissertation study in every respect save formulating a problem at the start" (Dillon 1982, 108).

Eliot Aronson (1977) once commented on the state of research in social psychology by quoting a short story written by J. D. Salinger. An aspiring young writer receives a critique of his most recent story from his brother, Seymour, who says, "You are really a terrific craftsman. You really know how to write. You really know how to put a sentence together; you've mastered the technique. You know how to take these sentences and string them together into paragraphs. Your stories are constructed beautifully. The one thing you haven't learned yet is what to write about, and that's a really important problem" (194). Masters (1984) argues that seeing social relevance in research is "an acquired skill, one that is not typically propagated in graduate education, and at this point in time most students and faculty probably lack it" (856).

Somewhere between the macro- and micro-levels of exploration exists the everyday world of human affairs, where applicable behavioral science theory is needed to contribute to the solution of serious social problems of local, national, and international scale. It would seem that behavioral scientists must have something more to offer to the creation of harmonious relations between peoples of the earth, and between them and the planet itself. Directly pursuing these concerns would be the most courageous—or creative—act that behavioral science could choose.

Beyond asking socially useful questions, however, behavioral scientists could be more creative by being more exploratory in the methods they adopt to answer the questions they have posed. Excessive concern with propriety of method can drive out imagination. Einstein is reported to have said of his own research (Thayer 1983), "There is no logical way to discover these elementary laws; there is only the way of intuition" (87). Einstein discovered his general theory of relativity not as the result of careful experimentation, but on the basis of symmetry and mathematical elegance. Methodologically, he ran counter to prevailing scientific norms of vertical thinking. There is a great difference between a truly innovative scientist and a scientizer. The scientizer becomes fixated on detail at the expense of vision. The scientism of the scientizer is a faith, an ideology. An increasingly empirical science allows for the exploration of alternative modes of knowledge-generation. New ideas are needed, and historically these tend to be born more out of lateral thinking. When Thomas Edison was once asked about his rules of procedure he is said to have replied, "Rules! Hell! There ain't no rules around here! We're tryin' to accomplish somethin'!" (Thayer 87).

The "Law of the Instrument" (Rosnow 1981, 115) is that if you give a child a hammer everything will become something that needs pounding. Behavioral scientists are at least as subject to this law as anyone else. Ruth Ann Clark (1979) has commented on this tendency to apply one favorite, habitual, or only-known method to research questions: "Too often, however, the method rather than the research question seems to be the controlling force in a study. If a researcher is familiar with a particular measuring instrument or statistical technique, he or she may seek questions amenable to study by such methods rather than searching for techniques to answer substantial questions of interest" (52). Methods begin to dictate the questions asked and the answers obtained. Clark continues, "Ideally, we should consider widely divergent alternatives to answering the question before selecting a method. Too often, however, this is not the case" (58). Why are these "widely divergent alternatives" of method not more energetically sought by behavioral scientists? One might answer, because the search for alternatives is a function of lateral thinking. Behavioral scientists have not had the sort of lateral-thinking training in graduate school that would stimulate them to think creatively about methological options.[1]

As an individual, it's easy to get stuck in a rut. So it is with scientists and therefore science. When humans become routinized in habits and preferences, they become oblivious to the possible appropriateness and advantages of other ways of doing things. As we lock-in to certain patterns of perception and performance, we automatically lock-out other possibilities (LOLO = as we lock-in, we lock-out). Each system has its sanctioned rules of procedure, and deviation is not encouraged. Science is more rule-laden than the typical system, constituting a system of rules for the verification of statements. Scientists then have not only the usual human tendency to fall into ruts, but the very rules by which scientists play disavow rule violations. If one is a scientist, one either plays by the usual rules or not; if one doesn't, one is not being scientific, and if one does, very often one is not being creative.

Kurt Lewin, one of the founding fathers of social science research, was motivated by this basic conception of the "good" scientist (Cartwright 1951): "He discloses the basic character of science as the eternal attempt to go beyond what is regarded as scientifically accessible at any given time. To proceed beyond the limitations of a given level of knowledge the researcher, as a rule, has to break down methodological taboos which condemn as 'unscientific' or 'illogical' the very methods or concepts which later on prove to be basic for the next major progress" (xv). The researcher who can successfully do this is exercising his or her capacity for scientific creativity. It has been said that any science's methods are the definitions of its limits. The more open a science can remain to multiple methodologies and supplementary epistemologies, the greater the possibility of increasing the domain, precision, and potential usefulness of its theory.

It might be said that the most creative act would not be to collect yet another piece of datum, but to synthesize more of the knowledge that already exists. This can be every bit as creative as another dip into the subject pool. To bring together pieces of data into a new composition can clarify. Too often we disvalue the act of summarizing and connecting. Each investigator wants to launch out anew, to bring something original into being, yet this can also be achieved through the ordering of previously obtained data and teasing-out new lines of thought and insight. *Psychological Abstracts* alone reports over 25,000 new research studies on human behavior each year. This proliferation can lead to a disparate hodge-podge of seemingly disconnected findings. It is the creative investigator who can discover pattern, who can draw into greater unity that which had been far-flung. Otherwise, we drown in data and suffer meaning-lag, where the gap between vast amounts of information, on the one hand, and its implications and relations, on the other, grow exponentially further apart.

Combining present elements into fresh pattern is part of the essence of creativity. Consider the common household doorbell (Varella 1977): behind this creation are such principles as Ohm's law, electromagnetic effect, magnetic concentration at iron cores, remanent magnetism as a function of carbon content, the elastic property of springs, the insulating properties of wire coverings, and so forth. When the principles are creatively combined, there goes the doorbell. When the principles come together, new applications can materialize. We need researchers who are willing to ruminate upon a greater range of that which is known, in an effort to bridge between various of these islands of knowledge. We need problem-solvers, we need inventors, we need tinkerers, and we need probers. Suspension bridges, airplanes, and computers are each the result of an ingenious combination of principles derived from widely divergent areas. Alexander Graham Bell would never have invented the telephone if he had made it is his aim to specialize in the development of smoke signals (Varella 1977). Sir Isaac Newton is recognized as one of history's most influential scientists—among Newton's primary contributions to science for centuries to come was the organization of a mishmash of seemingly disconnected facts and laws that turned out to have application to a broad variety of physical phenomena and real-life problems. James Clerk Maxwell unified the laws of electricity and magnetism, again, by arranging a disordered set of phenomena into one comprehensive theory. Such synthesizers are needed in the behavioral sciences.

McGuire (1973) has suggested a drastic tactical change in the graduate education of behavioral researchers. He estimates that 90 percent of our training efforts have been directed to the hypothesis-testing phase of research instead of to the hypothesis-creation phase. To him, creative hypothesis-generation is the more important: "If our hypotheses are trivial, it is hardly worth amassing a great methodological arsenal to test them" (450).

I suggest that a course in creativity training be offered, through elective or by requirement, to those enrolled in doctoral programs in the behavioral sciences. This course would be expressly devoted to the development of lateral thinking in the asking and answering of research questions. I have heard of no such creativity-training course yet in any graduate behavioral science program in America. But it should exist nationally and young would-be researchers should be enrolled. In such a creativity training course, neophyte researchers would learn to establish greater contact with their right hemispheric capacities, they would become more "whole-brained," to use contemporary parlance for the acquisition of lateral as well as vertical thinking skills. Greater dialogue between the hemispheres, a more "fully-functioning brain," a more ambidextrous thinking style. These aspiring researchers would be trained to re-center their viewpoints, so that the familiar could be made to look strange, and the strange familiar (McKim 1980). They would learn to juxtapose seemingly polar concepts, to transform elements and mentally probe them in unconventional fashion. They would develop orthographic imagination, in which a mental object of thought is looked at from several directions. They would be helped to acquire associative flexibility through an assortment of creativity-calisthenics. Their vision would become invigorated through new types of perceiving, thinking, and feeling. These initiates into the scientific community, in sum, would be trained in seeing more totally. McKim has said this of *seeing:* "Seeing is encountering reality with all of your being. To encounter reality deeply, you cannot leave part of yourself behind. All your senses, your emotions, your intellect, your language-making ability, each contributes to seeing fully" (62).[2] The average behavioral scientist does not see in this sense. In my own days in graduate school, I had four courses in statistics and two or three in research methodology, and nowhere in that coursework can I claim schooling in creative vision. More recent crops of graduates and their writings do not lead me to believe that much has changed.

In a recent use of the statistical method of meta-analysis, Rose and Lim (1984) examined the results of the nearly fifty studies that measured the effects of creativity training and that used the Torrance Tests of Creative Thinking as the dependent variable. The majority of the studies analyzed were in the form of doctoral dissertations. The creativity program with the most consistent impact on the dependent variable was the Osborn-Parnes Creative Problem-Solving Program.

This program "profoundly affected" idea-production abilities, such that knowing whether subjects had received the training accounted for 78 percent of variance on "verbal flexibility," or the ability to shift from one approach to another in searching for appropriate problem-solving strategies. The reviewers conclude that "The substantial impact of Osborn and Parnes' CPS on verbal creativity combined with the conclusions from both Torrance's and Parnes and Brunelles' reviews provides strong evidence to support the effectiveness of this program" (21). It would seem, then, that at least a preliminary approach is in place that could be adapted to the task at hand, the training of behavioral scientists to search more creatively for worthwhile problems to solve, and to pursue these solutions in a flexible, innovative manner.

It is legitimate to ask at this point, can lateral and vertical thinking styles ever be reconciled into an enlarged science? Can those of us who write with one hand learn to write with the other, so to speak? This is a formidable task. Yet, whenever seemingly opposite forces come into dynamic conjunction and transaction, the interplay is intense and, if rightly handled, productive. Such a transaction carries tremendous power, if seeming chaos and contradiction can be withstood. To experiment creatively with combining these opposites can create new vantage points. Heisenberg had this to say about the complementarity of perspectives (Koestler 1972): "The concept of complementarity is meant to describe a situation in which we can look at one and the same event through two different frames of reference. These two frames mutually exclude one another, but they also complement each other and only the juxtaposition of these contradictory frames provides an exhaustive view of the appearances of the phenomena" (54–55). From another angle, it was F. Scott Fitzgerald who said, "The test of the first-rate intelligence is to hold two opposed ideas in your mind at the same time and still retain your capacity to function."

Every once in a while a perspective shift is so great that it constitutes movement into a new dimension of perception. New dimensions get added as new areas of experience appear that cannot be forcibly squeezed into the dimensions that we now use. A new dimension is not solely a rational or intellectual perspective, although this is part of it. One example of a dimension change, according to Gardner Murphy (1958) occurred between the fourteenth and fifteenth centuries in Italian art with a shift from two-dimensional to three-dimensional painting (151–154). Up from flatness, to arms that appeared to reach off the canvas toward the viewer, with shadow-crossed hills looming in the background and other forms advancing and receding in space. Another example of a dimension change during this time was Columbus' voyage beyond the second dimension. Of movements to new dimensions, Murphy said this: "The very nature of discovery lies not so much in more and more thorough exploitation of the material given by a given dimension, a process of infinite subdivision, but rather in the process of conceiving new dimensions" (249). He continues: "in each instance the period of great creativeness starts at right angles from a previous period of creativeness." Where do the limitations to such creativity lie? According to most who have studied the matter, our *assumptions* are our greatest limitations. If these are sufficiently challenged, a new dimension will sometimes emerge. Fresh perspectives and evolving dimensions are part of the on-going development of a scientist striving toward ever greater comprehension.

Personally, I enjoy a model of science that would include as a major construct "contraction-expansion" in alternating rotation (Wilson 1973). During the expansive phase, imagination is freed of as many encumbrances as possible. During the contractive phase, critical evaluation and decision-making are appropriate. The alternating pattern is the key element, not just within any single study, but within the entire behavioral sciences. Neither lateral nor vertical thinking should be our master; may we learn to cultivate *both* as the tools of a more emancipated behavioral science.

Notes

[1] As Timothy Haight has observed, "Beyond the training of graduate students, the process of collegial review in hiring, tenure, and publication decisions also exercises a stabilizing, or inhibiting, influence . . . when major differences in the definition of appropriate topics, methods, and theoretical approaches exist, the danger of the 'tyranny of the majority' exists also" ("The Critical Researcher's Dilemma," *Journal of Communication*, 33, 1983, 232).

[2] Rollo May also pursues this notion of total "encounter" as a central component of the creative process in his *Courage to Create* (New York: Norton, 1975).

List of Works Cited

Aronson, E. "Research in Social Psychology As a Leap in Faith." *Personality and Social Psychology Bulletin*, 3 (1977): 190–195.

Besemer, S. and Treffinger, D. J. "Analysis of Creative Products: Review and Synthesis." *Journal of Creative Behavior*, 15 (1981): 158–178.

Cartwright, D. *Field Theory in Social Science: Selected Theoretical Papers of Kurt Lewin*. New York: Harper, 1951.

Clark, R. A. "Suggestions for the Design of Empirical Communication Studies." *Central States Speech Journal,* 30 (1979): 51–66.

De Bono, E. *New Think: The Use of Lateral Thinking in the Generation of New Ideas.* New York: Basic Books, 1968.

Dillon, J. T. "Problem Finding and Solving." *Journal of Creative Behavior,* 16 (1982): 97–111.

Dubos, R. "Science and Man's Nature." In G. Holton (ed.) *Science and Culture.* New York: Houghton Mifflin, 1965.

Gordon, R. "Practical Theory." *Spectra,* 18, November 1982, 1–2.

Koestler, A. *The Roots of Coincidence.* New York: Random House, 1972.

Masters, J. C. "Psychology, Research, and Social Policy." *American Psychologist,* 39 (1984): 851–862.

McGuire, W. J. "The Yin and Yang of Progress in Social Psychology: Seven Koan." *Journal of Personality and Social Psychology,* 1973, 446–456.

McKim, R. *Experiences in Visual Thinking.* Monterey: Books-Cole, 1980.

Murphy, G. *Human Potentialities.* New York: Basic Books, 1958.

Powers, W. G. and Glenn, R. B. "Perceptions of Friendly Insult Greetings in Interpersonal Relationships." *Southern Speech Communication Journal,* 44 (1979): 264–274.

Rose, L.H. and Lin, H. T. "A Meta-Analysis of Long-Term Creativity Training Programs." *Journal of Creative Behavior,* 18 (1984): 11–22.

Rosnow, R. *Paradigms in Transition: The Methodology of Social Inquiry.* New York: Oxford University Press, 1981.

Thayer, L. "On 'Doing' Research and 'Explaining' Things." *Journal of Communication,* 30 (1983): 80–91.

Varella, J. A. "Social Technology." *American Psychologist,* 32 (1977): 914–923.

Weick, K. E. "Affirmation as Inquiry." *Small Group Behavior,* 13 (1982): 441–450.

Wilson, A. "Systems Epistemology." In I. Laszlo (ed.) *The World System: Models, Norms, Variations.* New York: George Braziller, 1973, 134–140.

Science, The Creative Process, and Brain Hemisphere Function

Elaine L. Kleiner

In an address delivered in 1918 before the Physical Society in Berlin on the occasion of Max Planck's sixtieth birthday, Albert Einstein remarked:

> The surpreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. There is no logical path to these laws; only intuition, resting on sympathetic understanding of experience, can reach them. . . . The state of mind which enables a man to do work of this kind is akin to that of the religious worshiper or the lover; the daily effort comes from no deliberate intention or program, but straight from the heart. (226-227)

Elsewhere, in an essay entitled "Physics and Reality," Einstein writes:

> Physics constitutes a logical system of thought which is in a state of evolution, whose basis cannot be distilled, as it were, from experience by inductive method, but can only be arrived at by free invention. The justification (truth content) of the system rests in the verification of derived propositions by sense experiences, whereby the relations of the latter to the former can only be comprehended intuitively. (322)

And finally, Einstein writes of the nature of modern science in his essay "The Problem of Space, Ether, and the Field of Physics":

> The theoretical scientist is compelled in an increasing degree by purely mathematical, formal considerations in his search for a theory, because the physical experience of the experimenter cannot lead him up to the regions of highest abstraction. The predominantly inductive methods appropriate to the youth of science are giving place to tentative deduction. . . . Here, too, the observed fact is undoubtedly the supreme arbiter; but it cannot pronounce sentence

> until the wide chasm separating the axioms from their verifiable consequences has been bridged by much intense, hard thinking. The theorist has to set about this herculean task fully aware that his efforts may only be destined to prepare the death-blow to his theory. The theorist who undertakes such a labor should not be carped at as "fanciful"; on the contrary, he should be granted the right to give free rein to his fancy, for there is no other way to the goal. His is no idle daydreaming, but a search for the logically simplest possibilities and their consequences. (282)

In these three statements, Einstein outlines a way of understanding the relationship between creativity and scientific thinking. On one hand, he identifies logic, induction, facts, and systematic thinking with "experimental science"; on the other, he associates laws, deductions, intuitions, sympathetic understanding, free invention, abstraction, theories, axioms, fancy, and daydreaming with "theoretical science." Or rather, Einstein identifies within scientific thinking itself two contrasting modes of information processing—one based on logic and the other upon intuition, one that develops systems and the other that intitiates such developments—the latter in common usage being considered "creative" and the former "critical."

In this, Einstein himself displays a remarkable, intuitive understanding of the direction that brain hemispheric research would take in the 1950s and 1960s. At the California Institute of Technology, Roger W. Sperry and his associates were to determine that "both (right and left) hemispheres of the human brain are involved in higher cognitive functions and that the two hemispheres employ different methods or modes of information processing" (Edwards vii), one that analyzes over time and the other that synthesizes over space much as Einstein had intuited (Levy 35). Believing epileptic seizures in some patients originate in one of the two cerebral hemispheres of the neocortex, neurosurgeons Phillip Vogel and Joseph Bogen attempted to confine seizures to one side of the brain by cutting through the corpus callosum, a bundle of some 200 million nerve fibers running between the two hemispheres. "Commisurotomy" proved successful in controlling such seizures. However, subsequent testing revealed that patients recovering from such surgery now possessed two apparently autonomous centers of consciousness, one in each hemisphere. If the left hand felt an object behind a screen, a patient could could not identify it verbally, although the left hand could choose the object again from among other items. Because speech resides primarily in the left hemisphere, which is in touch with what happens to the right hand only, this patient's inability to identify verbally an object touched only by the left hand was understandable. "Literally, in a split-brain patient the left hand does not know what the right hand is doing" (Ferguson 177). Further, the left hemisphere tended to analyze the whole into its parts, while the right saw the whole and was superior at spatial reasoning. Although animals have symmetrical brain hemispheres, this sort of "handedness" is evident even in human stillborn infants. Further studies revealed that the two halves of the brain may actually be "wired" differently, the right hemisphere having greater neuronal "interregional connectivity" and the left hemisphere having greater sequential neuronal organization (Rico 70-71).

At birth, the corpus callosum appears to be undeveloped and the two brains do not interfere with one another, allowing the phenomenal ability to learn during infancy and early childhood. But gradually one hemisphere becomes dominant as the corpus callosum's nerve fibers grow the fatty myelin sheaths that enable it to conduct electrical impulses from one hemisphere to the other within the brain, reaching full development around the age of eleven (Rico 73).

Recent research suggests that rigid distinction between the two hemispheres may be an oversimplification. Although researchers remain convinced that the brain's left side controls the right side of the body and vice versa,

> their latest experiments are much less conclusive about how it divides up mental tasks. When volunteers were asked to speak out loud, more blood (labeled by radioactive tracers) flowed into their left hemispheres, indicating the expected surge of activity there. But the right side lit up too. Then the volunteers were asked to perform such spatial tasks as determining the angle of a line by comparing it to a chart. Again, both hemispheres lit up, although the right was more active. (Begley 43)

Examinations of mature patients with speech disturbances due to brain damage revealed that the minor hemisphere "could not follow a simple command to nod or smile; it could not comprehend pluralization, passives, or the future tense; it could not respond to verbs, adjectives, or nouns derived from verbs (e.g., teller, locker)" (Stross 62). It could, however, deal with negative or affirmative constructions and respond appropriately to concrete nouns—those kinds that emerge early in the history of a language (e.g., "Reh-pi," *light-dark* in the Hopi language), which Sigmund Freud called "primal words." It has therefore been suggested that early stages of language included forms of a concrete nominal nature before actual verbs were separated out from them as distinctly encoded forms. Speech production can be initiated only by the dominant hemisphere, but both hemispheres are capable of language comprehension—one fully and the other in part, perhaps only in nouns and relations to other nouns (Stross 62). There is also reason to believe that the minor hemisphere demonstrates greater interconnectivity with the midbrain's more primitive limbic system, the seat of emotional expressiveness. Right hemisphere damage therefore leads to the inability to express language with emotional nuances (Rico 79).

The classic experiment demonstrating differing capabilities of the two hemispheres was conducted by Edith Kaplan of the Boston Veterans Hospital Administration. In this test, a series of patterns was presented to a subject whose hemispheres had been surgically isolated from one another. The subject was asked to reproduce the model patterns by assembling colored blocks either with the right hand alone or with the left hand alone. Errors were equally frequent with either hand, but the kinds of error typical of each hand were quite different. The right-hand left-hemisphere assembled chains of individual blocks; the left-hand right-hemisphere assembled patterns of blocks more symmetrical and "beautiful" than the original model. This pattern-making quality of the right hemisphere has led researchers to give it the name "design mind."

Further experiments with split-brain patients described by Robert Nebes in *The Human Brain* have identified the role the right hemisphere plays in the creation of metaphors:

> A picture of a round cake on a plate is flashed on a screen to a split-brain patient's right visual field, which feeds into the logical left brain. The patient is then instructed to choose an object from a large array that is pictured with the cake. The left brain invariably makes the logical choice, such as a knife or a fork, for naturally you need one to cut the cake with, the other to eat it with. But when the same round cake on a plate is flashed to the patient's left visual field, which feeds into the right brain, the patient invariably chooses—a round straw hat with a brim! (Rico 188)

Perceiving similarity of shape in dissimilar things is not logical, but it is the essence of metaphor.

By contrast, left hemisphere thinking is computerlike:

> In a government-funded automatic-language-translation project, experimenters discovered that even the most elaborate computer is utterly baffled by fairy tales and metaphors. In asking a computer to translate "The spirit is willing but the flesh is weak" from English to Russian and then back to English, it came up with "The wine is agreeable, but the meat has spoiled." When given the proverb, "Out

> of sight, out of mind," the computer decoded it meant "Blind and crazy." (Rico 189)

The very nature of the left hemisphere thinking that makes sequencing of information possible may also have the effect of actually stifling creativity. The dominant left verbal hemisphere appears to censor behavior for social acceptability. Further, it doesn't want too much information about things it perceives—just enough to recognize and categorize. "Because the brain is overloaded most of the time with incoming information, it seems one of its functions is to screen out a large proportion of incoming perceptions" (Rico 68). This is a necessary process to enable one to create logical thought sequences, but it is less useful in enabling one to make sense of large arrays of information requiring perception of many details.

The implications of research on brain hemisphere function for understanding the creative process and the interactions between the sciences and humanities are two-fold. First, because the creative process appears to initiate in the right hemisphere, scientists must be trained not only in verbal, symbolic, and logical thinking, but also in spatial, relational, and holistic thinking—the kind of thinking characteristic of the arts. Secondly, modern neuro-physiology has discovered that although the right and left sides of the brain have specialized functions, nevertheless in all ordinary activities and especially in creative science, both sides of the brain are active. It has been noted that with the development of the individual towards fuller functioning, the EEG, or brain wave patterns, becomes more symmetrical, showing the same pattern on both sides. This integrated state is not simply a balance or alternation between two separate functions; it is not "half one, half the other" or "first one, then the other." It is rather the emergence of a new kind of energy, a new principle, symbolized by the "center" that is a generating force in itself. The corpus callosum connects the two hemispheres for two major purposes: to allow them to communicate with each other at the rate of thousands of impulses per second, and to inhibit this informational flow when it is necessary to focus the talents of one hemisphere alone on a task (Rico 71). Einstein himself practiced such inhibition, engaging from the age of fifteen on in what he called "thought experiments."

> In one thought experiment, Einstein imagined what a light wave would be like if he were an observer riding along with it. In another, he imagined a man in a falling elevator and how it would "feel" and what would happen to his keys, and so forth. Einstein asserted that

> only when these images became so clear that they were voluntarily reproducible could he laboriously transform them into communicable language. Here we have a compelling example of callosal inhibition of logical "sign" information from the left brain so that the right brain can seek out, discover, and stabilize its images.
> (Rico 71)

It is toward this higher mode of functioning that both the creative arts and sciences aspire.

List of Works Cited

Begley, Sharon, John Carey, and Ray Sawhill. "How the Brain Works." *Newsweek*, Feb. 7, 1983, 62.

Edwards, Betty. *Drawing on the Right Side of the Brain*. Los Angeles: J. P. Tarcher, 1979.

Einstein, Albert. *Ideas and Opinions*. New York: Bonanza Books, 1974.

Ferguson, Marilyn. *The Brain Revolution*. New York: Taplinger, 1973.

Levy, Jerre. "Psychobiological Implications of Bilateral Assymmetry." In Edwards, p. 35.

Rico, Gabriele Lusser. *Writing the Natural Way*. Los Angeles: J. P. Tarcher, 1983.

Stross, Brian. *The Origin and Evolution of Language*. Dubuque: Brown, 1976.

Neuropsychological Study of Talent

Loraine K. Obler

Since neuropsychological study of talent is a relatively new field, it is worthwhile reviewing the development of the neuropsychological paradigm over the past century in order to set the context for its application to the study of talent and exceptional abilities.

The goal of neuropsychological study is to understand the relation between human behavior and brain substrate. The neuropsychologist wants to know what is going on in the brain of an adult performing an activity, and also how the brain developed to permit it. The major methodology for studying these relations has been to observe and analyze the deficient behaviors of the brain-damaged patient and then to draw conclusions about normal activity. For example, if the aphasic brain-damaged patient has difficulty with the production of speech but not with comprehension, then we conclude that production and comprehension are dissociable components in the healthy performance of speech/language abilities. If the child but not the adult recovers language fully after a severe left-hemisphere lesion, we conclude that in the normal non-brain-damaged child the right hemisphere is able to take over language processing, but this ability is lost some time in young adulthood.

This paradigm has been applied to some case studies of individuals with exceptional talents who became brain damaged. Schweiger (forthcoming), for example, reports on the several visual artists who lost the ability to draw three-dimensional figures, or who changed from a linear style to a more abstract style after a stroke. Judd (forthcoming) reviews the case of a composer who was no longer able to experience music affectively after a right-hemisphere stroke.

In most instances such studies have not yet questioned whether the components of the ability discovered through brain-damage would be those of any normal who spent some time in composing or painting, or whether they are components of the famous and highly skilled artist who has developed them due to biological proclivities or to years of exercising the ability.

A second, newer approach to the study of talents reverses the standard neuropsychological methodology. Instead of looking at the components of deficient abilities against the background of spared abilities, the exceptional ability is analyzed against the background of merely normal abilities in the prodigy, or less than normal abilities in the case of the *idiot savant*.

Gardner exemplifies this methodology in his book *Frames of Mind: The Theory of Multiple Intelligences* (1983). Gardner demonstrates that the seven types of "intelligence" he has isolated exist as independent categories. One of the arguments he uses is the fact of prodigies and *idiot savants*. If we have the report of an autistic boy who can build sophisticated electric devices (214), or recall music (121), or a girl such as Nadia who draws like a talented adolescent (188), and these individuals have few or no other exceptional or even normal abilities, that is a good argument that they are isolated capabilities. This should be true even for other individuals in whom the abilities do not stand out so starkly but are seen in the context of other normal abilities.

Smith's book, *The Great Mental Calculators: The Psychology, Methods, and Lives of Calculating Prodigies Past and Present* (1983), demonstrates that calculating abilities can occur in *idots savants* as well as in apparently normal individuals, and even in mathematical geniuses such as Gauss and von Neumann. Had we studied only the mathematical geniuses with the skill, we might have spent a long time looking for the connection between math genius and calculating ability. Once we recognize that some math geniuses and some autistic children have exceptional calculating ability and others do not, then we can appreciate that it is probably an independent skill.

In addition to demonstrating the independence of the skills and talents, however, it is useful to conduct more detailed neuropsychological testing of prodigies and *idiots savants* in order to discover both the components of their talent and the neuropsychological skills that may be dissociated from or associated with it. A number of such studies will be included in Obler and Fein's book *The Neuropsychology of Talent and Special Abilities*. In that book Novoa, Obler, and Fein report, for example, the case of CJ, an exceptional second-language learner. CJ had easily learned four languages after puberty (when most humans lose the ability to learn a language with the proficiency of a native speaker). We administered a series of neuropsychological tests to CJ, including tests of IQ, memory, visuo-spatial skills, and language aptitude.

Quantitative analysis of the tests demonstrated the sort of scatter that makes such a subject interesting (had he done well on all our tests, we would not have been able to draw conclusions). For example, CJ had an IQ on the Wechler Adult Intelligence Scale of only 107, so we could conclude that exceptional IQ is not crucial to exceptional second language learning ability. Also on the Modern Language Aptitude Test, CJ performed in the highest percentiles on all the independent subtests except the test of ability to abstract grammatical rules. While such an ability may contribute to some good second-language learners' skills, we deduce that it is not crucial in order to attain the proficiency of a native speaker.

Qualitative analysis of CJ's responses demonstrated that he had a preference for responses that relied on form rather than meaning. On the similarities subtest of the WAIS, for example, when asked what *work* and *play* had in common, CJ responded that they both had four letters. When asked what a poem and a statue had in common, CJ noted that they both have lines. Whether we view such responses as excessively literal or excessively creative, they are not usual responses and thus he was scored down for them on the IQ test. However, such a preference for form rather than meaning, we suspect, is a valuable component to CJ's second-language learning ability.

Also important was CJ's superb verbal memory. While he did not have a good memory across the board (for example his memory for drawings was no better than normal), CJ had very good intermediate-term memory for words. On the California Verbal Learning Test, the subject is asked to remember a list of sixteen words. CJ performed only normally under the standard test procedure of repeating back the words. Interestingly, unlike normals, he did not use the semantic grouping that the list makes possible since it is composed of four categories of words. However, after two weeks, CJ still recalled the majority of the words on the list while normals can recall only a few. So we have narrowed in on the sort of verbal memory that seems to enable CJ's language learning.

Such case studies, it must be noted, are particularly good at showing *dissociations*. We can without question conclude on the basis of the single case study of CJ that IQ as it is standardly measured and the ability to abstract grammatical rules are not crucial for exceptional language learning. But the evidence for *associations* between certain abilities and the ability under examination is more circumstantial. While it makes sense that a specific ability to remember words apart from their meaning categories and a preference for form rather than function are important in CJ's language learning ability, it is conceivable that the next talented second-language learner will not have these skills. Thus to demonstrate associations, we need large group studies.

The third important approach to neuropsychological study of talent is the approach indicated by Norman Geschwind before his untimely recent death. Geschwind (1985) observed that certain phenomena—including talents and a set relating more obviously to brain lateralization such as handedness and dyslexia—cluster in certain families. He theorized that fetal hormonal environment accounted for the unusual development of cortical connections in individuals in these families. In particular he suggested that testosterone levels interact with the "normal" development of the two hemispheres (i.e., the right hemisphere in advance of the left hemisphere) resulting in a different developmental pattern of the hemispheres. Cells "destined" for one area of the brain, by this analysis, either end up elsewhere or die off in patterns different from those that usually follow birth (Galaburda 1983). These cellular divisions then would account for the talents as well as the disabilities linked in the family constellation, and they should explain certain combinations of talent and disability, such as dyslexics who are particularly good at mathematical or visuo-spatial abilities.

Geschwind's theory would also account for some of the gender disparity seen in certain of the talents. With mathematical prodigiousness (Benbow and Stanley 1984) one sees more boys, where with exceptional language abilities, girls excel. Geschwind (1985) explains these sex differences by testosterone excreted by the male fetus in addition to that supplied by the mother. He takes great pains to emphasize that his theory is not simply a deterministic one. Stating that a talent or disability is biologically or genetically based does NOT mean that it will necessarily develop or fail to develop regardless of the conditions in which a child grows up. Certain environmental factors are crucial for the manifestation of talent, as they are for the manifestation of disability (Geschwind 1983).

In order to test Geschwind's theory, the first approach is to analyze questionnaires sent to individuals with the talent in question and to determine how often they show the cluster of related phenomena as compared to a group of controls who do not show the talent. However, while such research may reinforce Geschwind's observations of the cluster, it will not speak directly to the theory by which he explained it. To do that, one might start with post-mortem examinations of the brains of talented individuals, along the lines of those carried out on dyslexics by Galaburda (1983), which clearly demonstrated unusual cortical and sub-cortical cellular development in several dyslexic individuals. Interestingly enough, such research was started at the end of the past century in the early days of behavioral neuroanatomy, when groups of European scientists donated their brains for study by their surviving colleagues. However, the techniques for studying brain anatomy were less sophisticated at that time, and the theory fell into disrepute when the extra gyri that had been seen in certain geniuses were also discovered in certain morons, and other highly intelligent men were discovered to have no obvious extra gyri (Gould 1981). Newer methods of studying cell development enable the study of more basic levels of brain development in ways that our colleagues at the turn of the century were unable to, and therefore Geschwind recommends a return to such research in order to further the study of learning disabilities and, I would add, of special abilities.

In order to discover the brain-behavior relations underlying talent, then, we must follow several paths. We must study talented individuals whose talent has been modified (or not) as a result of circumscribed brain damage. This will determine components of the talent and gross brain areas underlying them. We must analyze neuropsychological test results of healthy individuals in whom talents stand out beside other merely normal or poorer than normal performance. This will show which cognitive abilities dissociate from the talent, and which may be linked to it. We must analyze familial constellations of talent and disability as they relate to cerebral lateralization and potentially to fetal and post-birth environment in order to suggest genetic and biological features related to talent. And we must undertake post-mortem neuropathological analyses of talented individuals who should evidence unusual cell patterning in order to see the neuroanatomical structures that serve as substrate to the talent. Given the same hundred years of intense research that aphasia has enjoyed, many of the secrets of the brain bases for talents will no doubt be revealed to us.

List of Works Cited

Benbow, C. and J. Stanley. Sex Differences in Mathematical Reasoning Ability: More Facts, *Science*, Vol. 222, 1029–1031, 1983. Galaburda, A. Definition of the Anatomical Phenotype, in C. Ludlow and J. Cooper, eds. *Genetic Aspects of Speech and Language Disorder*, New York, Acadmic Press, 1983.

Gardner, H. *Frames of Mind: The Theory of Multiple Intelligences*, New York, Basic Books, 1983.

Geschwind, N. The Biology of Cerebral Dominance: Implications for Cognition, *Cognition 17 (1985): 193–208.*

Gould, S. J. *The Mismeasure of Man*. New York, Norton, 1981.

Judd T. The Neuropsychology of Exceptional Musical Abilities, in Obler and Fein, *The Neuropsychology of Talent and Special Abilities* (1985).

Novoa, L., L. Obler, and D. Fein, *The Neuropsychology of Exceptional Second Language Acquisition: A Case Study*, in Obler and Fein, *The Neuropsychology of Talent and Special Abilities.*

Obler L. and D. Fein, eds. *The Neuropsychology of Talent and Special Abilities*, New York, Guildford (forthcoming).

Linguistic Creativity: A Common Problem

Wayne D. Owens

Scientists, philosophers, and literary artists share one common problem—how to say what has never been said. The fact that modern scientists are relative latecomers to the problem in no way mitigates its importance. Quite the contrary, Werner Heisenberg and Max Born have aligned twentieth-century physics respectively with poetry and philosophy. Heisenberg writes, "When it comes to atoms, language can be used only as in poetry" (Bronowski 340); and Born writes, "I am now convinced that theoretical physics is actual philosophy" (Bronowski 364).

The problem is creativity in language. Its scope can be circumscribed by questions. When something is experienced for the first time or something is experienced to be different from what or how it had previously been experienced to be, how can it be said? How does language change in order to reflect a changed state of affairs? How does it then become public property and available for re-telling?

Many philosophers have sustained extensive interest in language. But most have foundered on the problem of creativity. Noam Chomsky, for example, echoes only the common sentiment of philosophers and linguists when he says, "What I have called elsewhere 'the creative aspect of language use' remains as much a mystery to us as it was to the the Cartesians who discussed it, in part, in the context of the problem of 'other minds'" (*Reflections on Language* 138–139). Such an admission seems to obviate any detailed investigation of Chomsky's generative transformational grammar for the issue of linguistic creativity. Yet, it is appropriate to reflect briefly on the significance of Chomsky's point, since some have dismissed his work as mathematical trivia with no bearing on the question of creativity, while others have hailed it as revolutionizing linguistics and the study of language in general.

Chomsky's generative transformational grammar has been pretty much restricted to the study of syntactic competence, and he has largely ignored the study of linguistic performance, although competence and performance are not exclusive categories. The "creative aspect of language use" Chomsky allocated to the domain of performance rather than competence, as is evidenced in his specification of it as "innovative in scope, free from the control of external stimuli or detectable physiological states, coherent and appropriate to situations" (*Dialogues* 28). "Linguistic theory," on the other hand,

> is concerned primarily with an ideal speaker-listener, in a completely homogeneous speech-community, who knows its language perfectly and is unaffected by such grammatically irrelevant conditions as memory limitations, distractions, shifts of attention and interest, and errors (random or characteristic) in applying his knowledge of the language in actual performance.
> (*Aspects of the Theory of Syntax* 3)

The assumption of such a speaker-listener may be profitable for gaining insight into the syntactic aspects of a language, but it remains an unreal abstraction yielding little understanding of creativity in language in a particular context.

Much of the problem of linguistic creativity has to do not with syntax but with words or, better, the coming-to-be of words. Consider the following three sentences:

(1) anyone lived in a pretty how town (e. e. cummings)
(2) Any hadron containing a different number of "charmed" antiquarks would also carry a nonzero value of this property of "charm." (Gerald Feinberg)
(3) The dif-ference lets the thinging of the thing rest in the worlding of the world. (Martin Heidegger)

The first was written by a poet, the second by a scientist, and the third by a philosopher. All make syntactic sense in English. Yet, in each case, the authors strive to make language express an insight. Their creativity has more to do with the words themselves than with the syntactic relations; in each case, the syntax is standard English, despite the fact that the third sentence is translated from German. No amount of theorizing about competence is likely to explain the personal relationship an individual speaker has with his language, a relationship that shows itself best when the speaker is faced with the task of saying something new with an old language.

Chomsky's biology-based theories may yet yield a satisfactory explanation of some types of linguistic occurrences. But until more attention is paid to semantic issues and actual linguistic performance, it is unlikely that generative transformational grammar will yield essential insights into linguistic creativity.

Maurice Merleau-Ponty has concentrated his attention on the problem of the creativity in language and, I believe, suggested a supplement to generative transformational grammar. Merleau-Ponty's reflections on language focus on the experience of the speaking subject. Moreover, as a phenomenologist, Merleau-Ponty takes a special interest in the role of consciousness in speaking performance. Finally, he provides a suitable vocabulary for discussing what happens in linguistic creativity.

"Significations," Merleau-Ponty writes, "never free themselves completely from the intercourse of signs" (*Signs* 45). Signs by themselves, he had learned from Saussure, do not directly express a meaning. A sign, a word, from the beginning signifies only its difference from all other signs. Significations come into being through the interaction of signs. Only a grouping of signs has meaning:

> The reason why a language finally intends and does say something is not that each sign is a vehicle for a signification which allegedly belongs to it, but that all the signs together allude to a signification which is always in abeyance when they are considered singly, and which I go beyond toward without their ever containing it.
>
> (*Signs* 88)

Merleau-Ponty kept trying to pin down the indirectness of linguistic meaning with such expressions as "meaning arising at the edge of signs" (41), "meaning appears . . . in the interval between words" (42), "language expresses as much by what is between the words as by the words themselves" (45), "all language is indirect or allusive" (43), and "the meaning of expressions . . . is a lateral or oblique meaning which runs between words" (46).

But how does the convergence of signs take place to produce a particular signification in the first place? The answer is the heart of Merleau-Ponty's account of how language can be creative. It has three parts—the motivation to signify, the structures mediating the significative intention and verbal articulation, and the "mechanism" whereby the significative intention becomes verbal.

Why do we speak in the first place? Why speak at all? MerleauPonty's answer is unequivocal:

> Speaking is not just my own initiative . . . because as speaking subjects we are continuing, we are resuming a common effort more ancient than we, upon which we are grafted to one another and which is the manifestation, the growth, of truth.
>
> (*Prose of the World* 144)

The *truth* that Merleau-Ponty refers to here is not to be confused with the truth of correspondence; that is to say, it has the fundamental sense of revelation, manifestation, showing, and pointing out. As such, truth is not perfect or timeless but rather situated. "The highest point of truth is still only perspective" is the way that Merleau-Ponty puts it (*Prose* 132). In general, truths are revelations that are recognized and institutionalized in a particular linguistic culture. They invite further investigation, and may be supplanted by more adequate revelations in the same way that the Newtonian theory of gravity was supplanted by Einstein's general theory of relativity.

We speak then because truth matters and because its pursuit is a historical and social affair. The motivation to speak is something we are subject to, not subject of.

"The will to speak is one and the same as the will to be understood" (*In Praise of Philosophy* 55). The will to be understood situates the speaker within a linguistic community. With special emphasis on creative speech, Merleau-Ponty writes

> For that speechless want, the significative intention, it is a matter of realizing a certain arrangement of already signifying instruments or already speaking significations . . . which arouse in the hearer the presentiment of a new and different signification, and which inversely (in the speaker or writer) manages to anchor this original signification in the already available ones. (*Signs* 90)

The system of "already signifying instruments" includes morphology, literary genres, types of narrative, and modes of presenting events. All these in large part govern how the will to speak can be fulfilled.

Given the possibility of creative use, it is clear that language is not a closed system but rather an "open whole" (18), a system in development, (86), "a moving equilibrium" (87), a "logic in contingency" (88), and "an oriented system which nevertheless always elaborates random factors" (89).

The central question of the present inquiry though is how a new and different signification can come to be. How is it that speech "gropes around an intention to signify which has at its disposal no text to guide it" (*Prose of the World* 45)?

This questioning will be recognized as somewhat unorthodox. Ordinarily, we would say that the speaker gives the intention body and makes it concrete. Merleau-Ponty's terms indicate that he underscored a passive, receptive side over which the speaker has only limited control. This passive, receptive side is that respect in which language intrudes in any particular speaking event:

> The words and turns of phrase needed to bring my significative intention to expression recommend themselves to me, when I am speaking, only by . . . a certain style of speaking from which they arise and according to which they organize without my having to represent them to myself. (*Signs* 88)

Words, that is, suggest themselves and activate other words according to the rules governing the language or, what is more likely, the style of speaking within the language, where rules may be in force to a greater or lesser extent. To describe the self-suggestion of words and turns of phrase, Merleau-Ponty refers to "the spontaneity of language," words being "torn from me by what I want to say" (*Signs* 75), and "the leap . . . from already available significations to those we are in the process of constructing and acquiring" (*Signs* 95).

The key concept for getting at the process of origination in language speech Merleau-Ponty borrowed from Andrè Malraux—"coherent deformation." Creative speech must be coherent insofar as the speaking intention must preserve the "spirit" of the language in order to be understood, but a deformation of the language in order for a new signification to come to be. The phrase "coherent deformation" thus expresses the necessity of both the passive and the active sides of creative speech from the point of view of consciousness. The freedom that the "open whole" of language offers the speaker is limited, all the way from the symbols or marks used in the writing system or the smallest units of speech that distinguish one utterance from another to accepted modes of presenting events. Despite the restrictions, however, the system allows considerable latitude in what can be said, and this latitude is in turn referred to the power of the speaker to say something new.

Although Merleau-Ponty does not offer examples of coherent deformation, it is not difficult to imagine what he means. One could use standard terms and adapt them to new usages; one could create neologisms or compound words and employ metaphors toward new meaning; or one could borrow words from other contexts not previously used within one's discipline. Moreover, the creative poetic, scientific, and philosophical expressions mentioned earlier are themselves examples of coherent deformation in action.

Merleau-Ponty carried his analysis beyond creative speaking to what happens after it has occurred. To denote the process by which creative linguistic expressions become familiar and in the public domain, Merleau-Ponty employs the word *sedimentation*. Every act of creative speech is potentially an exemplary type. But not every such expression is likely to become sedimented. In many cases, perhaps most, they quickly disappear. Yet it is necessary that some acts of creative speech and their original significations do undergo sedimentation. Original significations settle into a cultural world only if they are comprehended, widely enough accepted as true, and passed around. "Truth is another name for sedimentation," Merleau-Ponty says (*Signs* 96). But the converse is also true: sedimentation is the condition of the possibility of the endurance of truths and therefore a cultural tradition.

Perhaps the most important role of sedimentation for the study of linguistic creativity is that the process of sedimentation forms the horizon within which new words and the redefinition of already operative words are integrated.

Merleau-Ponty borrows a word from Edmund Husserl to designate the "fecundity of the products of a culture which continue to have value after their appearance and which open a field of investigation in which they perpetually come to life again" (*Signs* 59). The word is *stiftung*, which means foundation or establishment. The sense Merleau-Ponty breathes into the word has to do with the necessity of a future, the invitation to a sequel whereby our grasp of new truths becomes more complete by being anchored in the successes of the past.

Sedimentation and *Stiftung* then denote the possibility of further creative speech and the conditions for the possibility of the historicality of language.

There is a certain impersonal autonomy at work in creative linguistic activity over which the speaker or writer has limited control and in the face of which he must assume a particularly passive, receptive stance. The original prerogative of any speaker is a willful, silent openness to language, an openness geared toward letting language arrive, with no guarantee that it will. Yet, there is also an active role for the speaker to play, namely coherent deformation.

While the number of occasions for linguistic creativity may be fewer for the scientist than for the poet or philosopher, scientists are nevertheless often faced with the need to say what has never been said. Two obvious areas are the naming of new entities or phenomena (*matter, particle, atom, quark, organism, cell, ego, virus, quasar,* etc.) and expressing their relations or interactions (*gravity, electromagnetism, strong, weak, charm, natural selection, neurosis, illness, stress,* etc.) All such cases, as far as I can determine, are products of coherent deformation.

The idea of sedimentation refers to the way that creative speech becomes part of a system. Applied to the sciences, it refers to the way a technical vocabulary develops or is built over time. Sedimentation occurs in the sciences when an original creative linguistic occurrence is commonly accepted as revealing something actually happening in the world. The fact that many of the words that name entities or phenomena and all the words that name their interactions refer to what is invisible is no liability to the scientist. The sedimentation of creative linguistic expressions often occurs if the assumption of an entity to which the expression refers helps explain phenomena that are visible. This is, I take it, what Heisenberg meant when he wrote, "When it comes to atoms, language can be used only as in poetry," and what Born meant when he wrote, "I am now convinced that theoretical physics is actual philosophy."

Linguistic creativity in the sciences always means that words perpetually come to life again. It establishes and invites a future where what it reveals is either confirmed or supplanted. The duration of sedimentation is determined by the adequacy of the foundation (*Stiftung*).

Merleau-Ponty, it seems, has offered some fundamental insights into linguistic creativity. These apply directly to the work of scientists: his insights into the autonomy of language and the vocabulary he provides to denote what happens in and after the occurrence of linguistic creativity (coherent deformation, sedimentation, and *Stiftung*) aid us in understanding and explaining part of the scientific enterprise.

List of Works Cited

Bronowski, Jacob. *The Ascent of Man*. Boston: Little, Brown, 1973.

Chomsky, Noam. *Aspects of the Theory of Syntax*. Cambridge, Mass.: M.I.T. Press, 1965.

———. "Dialogues with Noam Chomsky." In Perret, *Discussing Language*. The Hague: Mouton, 1975.

———. *Reflections on Language*. New York: Random House, 1975.

Merleau-Ponty, Maurice. *In Praise of Philosophy*. Trans. John Wild and James M. Edie. Evanston: Northwestern University Press, 1963.

———. *The Prose of the World*. Trans. John O'Neill. Evanston: Northwestern University Press, 1973.

———. *Signs*. Trans. Richard C. McCleary. Evanston: Northwestern University Press, 1973.

Panel Topic

The Sciences and Human Values

The Unity of Creativity and Its Significance to Science and Social Progress

Alfred Kracher

Within our society, creativity is generally regarded as something desirable, a human quality that deserves to be encouraged, developed, and protected from undue restriction. Such an attitude implies that the individual creative act contributes in some way to the common good. Being creative is not seen as an isolated, individual phenomenon, but as participation in a social process—a process thought to be capable of changing society in a beneficial and desirable way.

Behind such an estimation of creativity as socially valuable lies an apparent paradox: we are used to thinking of the creative act as internal to the creative personality, and thus a phenomenom of extreme individuality. At the same time, creativity is thought to drive scientific progress, which requires the existence of an identifiable scientific community. Somehow any individual accomplishment has to make itself known to this community, be accepted by it, and through it exert its influence on society.

By *creativity*, it should be clear that I mean more than just an individual psychological phenomenon. Specifically, I will argue that creativity is indivisible, that the same creative process is at work in science, art, and other creative endeavors, and that this "unity of creativity" is reflected not only in the mental processes of the scientist or artist (which are not my concern here), but also in the way in which their activities interact with their peer communities and with society at large. Such a view, I would argue, has practical consequences as to how science should be practiced and taught.

Most artists and philosophers seem to assume the existence of a unitary, identifiable creative process underlying both arts and sciences, but within the scientific community support for this view is far from unanimous. Particularly, the perception of science by the general public is dominated by the view that science is a phenomenon *sui generis*, somehow exclusively relevant to reality in a sense that art or religion, for example, are not. This perception is partly due to the "social materialism" of our times, which regards the technological advances attending scientific progress as not only superior to but somehow "more real" than the more intangible values of the fine arts. This is not merely a public misunderstanding of science, but a view deliberately popularized. This view is not consistent with modern theory of science, which has found its most famous expression in Kuhn's *Structure of Scientific Revolutions* [*1*]. Kuhn acknowledges that science and society are interdependent, particularly at certain historical stages. Science progresses through alternating periods of *normal science* and *revolutions*. Revolutions change not only the content but also the rules, the "language" of science. Therefore methodological and philosophical issues become more important during revolutions, and influences from outside the scientific community take on greater significance.

If the individual scientist's creativity is the driving force of scientific progress, then what Kuhn is describing is how the creative act of the individual is integrated into the scientific community and thus can become socially relevant. But if we take the unity of creativity seriously, Kuhn's concept should *mutatis mutandis* be reflected in other creative activities as well. I think it makes sense to postulate that the characteristics of scientific progress, as formulated by Kuhn, follow from their function of turning individual creativity into socially relevant results and apply in similar ways to all areas of creative activity.

This thesis can be developed in two ways: first, by exploring the relationship between the psychology of creativity and Kuhn's sociology. Second, by taking a close relationship between the two as given, and looking to other fields of creativity, the fine arts for example, for phenomena corresponding to those that Kuhn described in the natural sciences.

A relationship between the individual creative act and Kuhn's scientific revolutions is suggested by certain distinctive parallels: the comparative suddenness of information being rearranged to reveal new meaning, usually followed by a protracted period of evaluation, the fact that psychologically as well as sociologically a new insight is obtained against a certain resistance, and so on. Paradigm shifts resemble a "collective gestalt switch," corresponding to an analogous concept in the psychology of creativity. An even more important parallel is the one between the period of mounting anomalies leading to a paradigm crisis and the labors of a creative personality to bring about the desired inspiration. Rollo May [*2*] characterizes this desire as *passion for form* and considers it the basis for the scientists' quest for theoretical elegance. In the unforgettable formulation of the German Romanticist E. T. A. Hoffman, the mind proceeds "aus dem Brüten in das Schaffen"[*3*]. The desire for theoretical elegance recurs in Kuhn's arguments as the criterion by which a new paradigm is recognized as superior. Kuhn was aware of the psychological parallels, although the example he cites (62–65) gives no indication of the fundamental role that the perception of anomaly and the associated tensions play in creativity.

The parallels between paradigms in science, schools of thought, styles in art, and so on, are obvious. Twenty years before Kuhn, the composer R. Sessions used almost identical formulations to describe musical composition within the framework of a reigning style [*4*]. A critical look at the differences remaining between their two analyses is even more instructive than the general parallelism: Sessions emphasized the vitality of a given style as a necessary prerequisite for stimulating creativity in its followers, a concept echoed by those of Kuhn's critics who regard normal science as more than mere puzzle solving, and disagree that *any* true creativity is necessarily related to anomalies.

While Kuhn is mostly concerned with the revolutions brought about by creative personalities, it might in this context be useful to consider the question, as it were, in reverse: does a genius invariably revolutionize the field he or she works in? The question entails another one: are there certain highly creative individuals who are destined to revolutionize whatever they tackle? or do we worship the heroes and heroines of past revolutions, without having any evidence that they were really more creative than their non-revolutionary peers?

In the history of the fine arts, deliberate rebellion against a reigning style is certainly not a prerequisite for highly creative achievements. However, in as much as paradigms are constituted by exemplars, the works of a genial artist, as exemplars of new style, must necessarily lead to a paradigm shift. Romanticism has generally viewed a revolutionary struggle as inevitable, but with regard to artists such as Mozart, for example, this is a distortion of historical fact [*5*]. Whether an artist becomes alienated from, and has to fight against, the rest of society is less a function of creativity than of how receptive or repressive the society is in which this creativity unfolds.

Creative scientists, too, can bring about tremendous advances seemingly without revolutionary struggle. A case in point is the steady development of evolutionary theory from the Darwinian revolution to the modern New Synthesis. Even in this case, however, some of the most creative contributors to this development were, like Mozart, initially all but ignored by their established peers.

A related question is whether contemporary science and art have perhaps dispensed with paradigms or reigning style altogether. Sessions thinks so but seems to deplore the fact (101–134). Feyerabend [*6*] seems to think that perhaps there never were any, and in any case there should not be, although he recognizes the inherent tenacity of theories. Other critics have pointed to apparently peaceful paradigm shifts [*7*] and claim that Kuhn's analysis, while correctly describing historical developments, may fail when applied to the scientific controversies of the present. I still consider it likely that future historians will find, in retrospect, that much of our present diversity of schools, in arts as well as in sciences, is rooted in some common, unchallenged paradigms. Of course, the discrepancies between Kuhn and Sessions may be simply due to intrinsic differences between music and the natural sciences. Nevertheless, these examples show how a concept of the unity of creativity allows us to evaluate statements on such diverse activities side by side, and derive new insights from the comparison.

Comparisons such as the preceding one are, of course, nothing new. But the relationship between creative activities goes even further. I think it can be demonstrated that impediments to creative freedom in one area invariably affect all other creative activities as well. The premise that human endeavors based on creativity are interconnected at a very fundamental level implies that science does not exist independently of other creative activity, and therefore it thrives or suffers with them.

Sometimes the attempt is made to promote one of these activities at the expense of another, for example by political systems that regard natural science as useful for providing means of power but look at the arts with suspicion. Historical evidence suggests that such selective promotion has always failed, in part because it is based on a mistaken view of the role and nature of creativity.

If one area of creativity tries to emulate and usurp functions that rightfully belong to another area, the resulting epistemological confusion can obscure the issues for rather a long time. This is quite clear in the case of religion: trying to derive scientific conclusions from theology is bad theology, as well as bad science, as we have learned from unfortunate experience [*8, 9*]. A similar case has been made for the arts: "when art begins to ape science, it becomes . . . an ape" [*10*]. But many scientists are unconvinced that science, too, can suffer by undue meddling into other disciplines; in fact, science is sometimes portrayed as if it were its business to meddle into everything. The assertion that such an attempt actually hinders the practice of science runs counter to the view of history preferred by most of those who write science history, and it is therefore difficult to find case studies.

A classical example of epistemological confusion about the relative role of science and theology is the debate attending the foundation of geology at the turn of the eighteenth to the nineteenth century [*9*]. What began as scientific dispute between the Vulcanist and the Neptunist hypotheses of rock formation took more and more to theological argumentation in the early 1800s. The issues were no longer whether rocks formed from aqueous solution or magma, but rather whether historical geology could be completely explained by referring to processes now in operation and acting continuously over long periods of time (actualism and uniformitarianism), or whether it had to resort to unknown, perhaps miraculous, causes (catastrophism). Inevitably, the suffocating political control that the English state-religion exerted over academic life became a factor in the debate, as can be seen from the fact that most uniformitarians came from outside the circle of church-controlled institutions [*11*], as well as the peculiarly "British" character of the debate, apparently not shared on the European continent.

Uniformitarianism was essential for any theory of evolution. But by adopting it, geology did not simply shed restraints in the quest for truth. The victory of the Darwinian paradigm, and the tenacity that had been required to defend it, established uniformitarianism as an article of belief, and later generations of geologists held on to it even where such faith was misplaced. The significance of catastrophic events in the history of the earth probably remains underestimated among geologists to this day. This can be seen, for example, in the dispute over features produced by the impact of large meteorites, such as Barringer Meteor Crater in Arizona and all lunar craters. Much of the support for impact processes was promoted by "outsiders" against the resistance of the geologic community: the meteorologist Wegener [*12*], the mining engineer Barringer [*13*], and the astronomer Baldwin [*14*], to name a few. The last in a long line of papers (published in 1953) to deny the impact origin on Barringer Crater specifically insists that it is a "geologic feature" [*15*], implying that something as catastrophic as a meteorite impact cannot be regarded as "true" geology. Today the debate still continues around topics such as whether mass extinctions at the end of the Cretaceous (the "death of the dinosaurs") could have been caused by meteorite impact, with paleontologists, as the true heirs of early Darwinism, accounting for most of the opposition.

The geological paradigm established in the nineteenth century was inadequate partly because it began its reign among epistemological confusion about the nature of scientific evidence and theology. What is of interest to our thesis of the unity of creativity is not the societal influence per se, but the way it restricted the subsequent practice of science. One can see this in two ways: organized religion was stifling creativity, and this had a long-lasting negative effect on scientific concepts developed at the time, or scientists tried to ape theology and produced less than optimal science in the process. Perhaps a little of both, but in any case this example suggests that between creative activities there exists a connection, mediated by processes operating within the societal matrix but outside particular fields, which is stronger and deeper than scientists usually suppose.

Not all such cases where the proper interaction between science and society breaks down are related to metaphysics. One celebrated case where prejudice within the scientific community seriously hampered progress is the rejection of meteorites in the eighteenth century. The unjustified scepticism, expressed mainly by members of the French Academy, about "stones falling from heaven" was certainly connected with an elitist attitude that automatically suspected common people, who might have observed meteorite falls, of the worst kind of superstition [*16*]. But it would seem as unjustified to blame this on the atheism of the French academicians as it is to blame it on Christianity, as later scientists, wiser in hindsight, have attempted [*17*]. In fact, perhaps the highest quality data from "social intelligence" [*16*] were collected by the emissaries of a bishop [*18*], and their validity denied by a scientist who was also a priest [*19*].

In conclusion, I would like to return to my initial assertion that regarding creativity as unified and indivisible has concrete practical consequences for science and science education:

(1) If we desire genuine creativity in science, it is probably counterproductive to further science at the expense of the humanities and fine arts. Doing so may temporarily enhance the efficiency of uncreative tinkering, but it will invariably alienate creative persons from society and will ultimately lead to repression instead of creative freedom.

(2) The way science is sometimes presented to the public, including beginning students, is to state dogmatically that science is not dogmatic. This has unnecessarily weakened the case of genuine science in confrontations with pseudoscientific movements. The problem might be avoided if scientists paid closer attention to the epistemological foundations of their own activity.

(3) I believe that if a society has generated creative works of great and lasting value, we have reason to regard it as a healthy, functioning society. Our own age, eager to present science as something superior to other areas of human experience and creativity, sometimes shows a peculiar, condescending attitude towards history. Works of the past, like Gothic Cathedrals for example, should suggest to us a society with functioning creative dynamics. To put down such as society as a Dark Age for not having a concept of science equal to our own seems to fall short of intellectual honesty.

(4) All areas of creative action require openness to the not-yet-known, the not-yet-achieved, but all are also in danger always of being abused by those who purport to know and have power. Dissent and

distrust between creative areas invite such repression. Prime examples are distrust of spiritual creativity (in a basic sense, religion) by scientists, and distrust of science by political activists who see it as invariably serving power.

(5) If creative achievement is the mark of a live society, our own age and situation may be some cause for concern. I am not certain to what extent such concern is justified, but if we consider ourselves the perfect, final world, what room do we leave for the creative imagination? Is perhaps the motto that "anything goes" incapable of stimulating creative action?

These issues do not have easy answers. Rather, the problems brought up here will themselves only be overcome by creative imagination and action.

List of Works Cited

[1] T. S. Kuhn, "The Structure of Scientific Revolutions." University of Chicago Press, 2nd. ed. 1970.

[2] R. May, "The Courage to Create." Norton, New York 1975.

[3] E. T. A. Hoffman, "Höchst zerstreute Gedanken" (first published 1813); in: Collected Works, edited by W. Harich. E. Lichtenstein, Weimar 1924, vol. 1, p. 37.

[4] R. Sessions, "The Composer and His Message," in A. Centeno ed., "The Intent of the Artist," Princeton University Press, 1941, pp. 101-134.

[5] H. Abert, "W. A. Mozart" (5th edition of Otto Jahn's Mozart), Leipzig: Breitkopf & Haertel, 1921. He contends that Mozart "toppled the old gods by just being there" without intending to be revolutionary (vol. 2, p. 19).

[6] P. K. Feyerabend, "Consolations for the Specialist," in: "Problems of Empiricism." Philosophical Papers vol. 2. Cambridge University Press, 1981, pp. 131-161.

[7] R. Pollie, "Brother, Can You Paradigm?" Science 83, July/August, pp. 76-77.

[8] A. Kracher, "Wege aus der Einsamkeit?" Die Furche (Vienna, Austria), 8 July 1981 (vol. 37, no. 27), p. 13.

[9] C. C. Gillispie, "Creation and Geology." Harvard University Press, 1951.

[10] Interview with Isaac Bashevis Singer, Time, 29 Oct. 1984, p. 94.

[11] M. Ruse, "The Darwinian Revolution." University of Chicago Press, 1979.

[12] A. Wegener, "Die Entstehung der Mondkrater." Vieweg, Braunschweig 1921.

[13] G. Foster, "The Meteor Crater Story." Meteor Crater Enterprises, Flagstaff, AZ, 1978.

[14] A summary is given by R. B. Baldwin, "An Overview of Impact Cratering," Meteoritics *13*, 364–379; see also E. T. Drake and P. D. Komar, "Origin of Impact Craters: Ideas and Experiments of Hooke, Gilbert, and Wegener." Geology *12*, 408–411 (1984).

[15] D. Hager, "Crater Mound (Meteor Crater), Arizona, a Geologic Feature." American Association of Petroleum Geologists Bulletin, *37*, 821–857 (1953).

[16] R. Westrum, "Science and Social Intelligence About Anomalies: The Case of Meteorites." Social Studies of Science 8, 461–493 (1978).

[17] F. Berwerth, "Die Meteoritensammlung des Naturhistorischen Hofmuseums als Born der Meteorkunde." Sitzungsberichte der Akademie der Wissenschaften in Wien, mathematisch naturwissenschaftliche Klasse, Abteilung I, 127, 715–795.

[18] Klobusiczky of Zagreb. Recounted by Berwerth [17] who misspells his name. Meteorite and document are pictured in: "Das Naturhistorische Museum in Wien." Residenz-Verlag, Salzburg, (Austria), 1979, pp. 69–70.

[19] (Abbé) F. X. A. Stütz, in "Bergbaukunde" (Leipzig, 1790), quoted in [16].

Philosophy, The Nature of Space Science, and The Justification of Space Exploration

Gonzalo Munévar

The Norwegian explorer Fridtjof Nansen once said, "The history of the human race is a continuous struggle from darkness to light. It is therefore of no purpose to discuss the use of knowledge—man wants to know and when he ceases to do so he is no longer man." The exploration of space should have appeared to him as an extraordinary challenge in which men and women can be their most human, especially if Werner von Braun was at all right in saying that the first moon landing was equal in importance to that moment in evolution when aquatic life came crawling upon the land.

But, contrary to Nansen's intuition, those claims about knowledge and the exploration of space bear philosophical examination. Not only does such exploration offer many opportunities for philosophical reflection, but philosophy in turn may also clarify some of the disputes that arise as we attempt to move into the cosmos. Some of these disputes are rather general: the justification of space exploration and the distinction between fundamental and peripheral science, for example. Others are internal to the exploration of space: whether the exploration should be manned, and whether it is possible to communicate with alien intelligent beings. A full treatment of these and other issues is impossible here. I will, instead, sketch some of the main arguments concerning the issue of justification in order to illustrate the interaction between the sciences and the humanities.[1]

To an explorer like Nansen it may not be clear why we should bother with justification. Why can we not just grab history by the tail and make it go where we wish to take it? Why should philosophy force us to reflection when action is so tempting? The most important reason why we should is that this issue has more than one side. There are those who scoff at the suggestion that man should wish to explore at the expense of things that they find of more consequence. Nor are they impressed by the notion that knowledge is essential to man, the title *Homo sapiens* notwithstanding. Most advocates of space exploration do attempt to provide some sort of justification. The standard positive argument emphasizes the many benefits that we derive from the program: weather satellites save lives and crops, communication satellites bring about economic expansion, and space technology spins off valuable products. But sometimes it is claimed instead that it is human nature or destiny to explore, as if what is were distinct from what ought to be.

Since the second of these suggestions is so problematic, let us concentrate on how much the standard case should impress the critics of space. There are two main kinds. The social critic often objects on humanitarian grounds: while enormous amounts of money are spent for space, people go hungry and without shelter. These critics may agree that space exploration is a good thing, just as they may agree that opera is a good thing. In either case, they would balk at the expenditure of billions of dollars a year while human problems go unsolved. Even though the claim that space has many benefits may go a long way toward answering the concerns of these critics, it may not go far enough, for it is not obvious how a probe of Jupiter, a mission to a comet, or interstellar flight can have tangible benefits. The standard case leaves out precisely the heart of space exploration: those very things that bring it an air of excitement and adventure, those elements of discovery and the satisfaction of intellectual curiosity that fuel the imagination and the enthusiams of its advocates.

The second main group of critics—which we may call ideological—do not think that space is a good thing. They view it as an extension of science, at least big science: an unwise activity that leads us to interfere with nature rather than live in harmony with it. Indeed, because of this massive scientific and technological interference, the world has come to the brink of catastrophe. Only a change of ideology or moral outlook can give us hope. The promise of space is then a siren song that diverts our attention at a crucial moment in our history. These critics are the heirs of Rousseau, who warned us, "Know once and for all that nature wanted to keep you from being harmed by knowledge, just as a mother wrests a dangerous weapon from her child's hands; that all the secrets she hides from you are so many evils from which she protects you."[2]

I do not mean to suggest that these two categories of critics exhaust all the positions that can be taken against space exploration. But a discussion of them will frame the problem and permit me to outline the role that philosophy has to play. At first we seem to be confronted by a conflict of values: the value of scientific knowledge, say, versus the value of fulfilling some other need. And we have also a conflict over whether the control of nature that science offers is good or not. The ideological critics may well argue that such control is partial and illusory, that in the long run we pay dearly for exercising it.

How can these conflicts be resolved? Notice that in each case some assumptions must be made about the nature of science. In the case of the social critics, how can an estimate of the value of scientific knowledge be made in the absence of some idea as to what science is? Why should we think that it is absurd to spend so much money for space rather than for something else? We often have only a gut feeling about how priorities should be allocated. But would not a different idea of the nature of science influence our gut feeling? As for the ideological critics, some particular notions about science must underly their claims that science interferes with nature and that it makes disaster inevitable. My suggestion is that proper understanding of the nature of science will alter the dispute about justification, that it will be seen then that scientific knowledge is of far greater value than the social critics had imagined and that its pursuit is by no means unwise.

A good way to introduce an appropriate mode of thinking about the nature of science is to contrast it with the standard position on the subject. According to that position, scientific knowledge is "objective"—that is, factual—and facts are the business of science. From this it presumably follows that the function of science is to collect facts about the universe, and the function of space science is to collect them from space. Lest it be thought that only unsophisticates hold such a view, let us remember that in the minds of a great many what separates science from other disciplines is that science has a method all its own. But the most prevalent notions of method boil down to a specification of the manner in which facts can tell us whether our theories and hypotheses should be accepted or rejected. According to some views, our theories should be proved or at least made highly likely by the evidence; according to others, a theory that conflicts with the evidence should be rejected. There have been several very elaborate versions of these and other views; but, in general, facts are thought to be the warrant of science.

As commonsensical as the standard position on the nature of science may appear, it is rendered unacceptable by recent developments in the philosophy of science. The lesson one learns from thinkers like Paul Feyerabend, Thomas Kuhn, Imre Lakatos, and even Karl Popper long before them, is that scientific views or theories can be said to be the spectacles through which we experience the universe.[3] According to Kuhn, for example, scientific views (he calls them *paradigms*) tell us what elements there are in the world, what relations exist between those elements, and thus what sorts of problems are meaningful in a particular science, as well as what kinds of answers are acceptable. To speak of science as a pair of spectacles that permit us to see the world is to speak metaphorically, to be sure. But that metaphor is by no means far-fetched. We should realize that without our scientific views we would simply be blind to many aspects of the universe. But scientific views give us more than pictures of the universe, they also provide means of interacting with it.

To illustrate how far this shift on emphasis can take us, let us consider briefly the manner in which Galileo surmounted one of the main obstacles of Copernicus' idea of the motion of the earth. In his analysis of the history of science, Paul Feyerabend explains how the Tower Argument was employed to show that the "facts" refuted the Copernican view. Suppose that the earth moves. If you then drop a stone from the top of a tall tower, by the time the stone hits the ground, the tower will have moved with the earth, and thus the point of impact will be a considerable distance from the base of the tower. For the impact to be as close to the base of the tower as it actually is, the stone should follow an oblique motion. But it obviously falls straight down. It is natural to say that the stone falls straight down, but this "natural interpretation" makes all sorts of theoretical assumptions, among them that motion is operational and absolute. Galileo offered a different perception that motion is relative, and the stone, the tower, and the observer share circular inertia with the earth. Thus the stone does not move straight down—it only appears to. In this manner, Galileo defuses one of the main objections to the Copernican view. Different views of the universe lead to different assumptions and hence to different views of what is to count as evidence. They also lead, as in this case, to a profound transformation of our understanding concerning what the world is like.

The standard position on the nature of science makes difficult a defense of space science. If radiation from a certain region of the cosmos has been coming toward us for millions of years, and will be coming for millions more, what is the hurry to put a telescope in orbit to observe it right now? If we place emphasis on the essential transformations of science and their consequences, however, we gain a new point of attack.

Scientific views are ways of looking at the world. But they are still our creations and thus imperfect. They always are in need of refinement, modification, or replacement altogether. The pressure for such changes comes from the double exposure to unusual circumstances (which force us to stretch our views) and to competing ideas (often developed to account for a few of those unusual circumstances, they then claim the right to extend to the entire field of the discipline). From these considerations follow two important consequences. The first is that what is at issue for science itself is not merely the addition of a few, or even many, interesting facts but the potentially radical transformation of our worldviews.[4] As we will see below, space provides a most extraordinary opportunity (and as I will argue an essential one) to effect those kinds of changes. And the second important consequence is that since our world views tell us what the world is like, they also determine ultimately what opportunities we can take advantage of and what dangers we can be warned about. Thus with changes in our world view comes the realization of new refinements and new solutions. To slow down or reject the process by which science grows amounts to a decision to deprive ourselves of much that is good and to prolong our exposure to unrecognized dangers.

These rather abstract considerations can be illustrated by concrete examples. Einstein began his career by asking "useless" theoretical questions such as, What would the universe look like if I were traveling on a light ray? In trying to satisfy his curiosity about this an other equally practical issues, he was led eventually to develop his theory of relativity and to take a most decisive role in pushing physics down the slope of the quantum. For some of his more specific accomplishments, several theoretical opportunities about light became possible. Applied to medicine, they have given us the delicate surgical procedures made possible by the laser. This medical advance began with a change of worldview in a field far removed from medicine at the time.

Imagine a crash program in Einstein's early days to have surgeons develop an instrument that could do what a laser can today. Is it reasonable to suppose that the point would have come when the well-supported surgeons would have recognized that the physics of the day had to be overthrown, and would they then have laid down the steps leading to the discovery of the laser? I think not.

Now it must be made clear that the possibilities inherent in space science to transform our worldview are by no means marginal. I will limit my discussion to some of the advantages of space over terrestrial science. Space science is defined as science carried out beyond earth's atmosphere, but its objects of study include the earth itself as well as very remote galaxies and quasars. Space science does not have a common subject matter but is an interdisciplinary activity of great scope that utilizes common tools (e.g., rockets and space probes) in the environment of space. What such an environment provides is a range of observation far beyond that possible from the surface of the planet. In astronomy, for instance, telescopes are very limited by the fact that the atmosphere absorbs most of the radiation that comes the earth's way. Some frequences are completely blocked (gamma-ray astronomy is possible only with space telescopes), and those that the atmosphere lets through do not give us distinct observations. We have been granted only a few small windows to the universe so far, but space astronomy can effect a most decisive change. The space telescope planned in connection with the space shuttle is only half the size of the one of Mount Palomar, but it will sweep a volume of space 350 times larger and produce images ten times finer! In general, space telescopes can detect the entire range of the spectrum. In combination with the gamma-ray satellites, they will give us a much deeper look at a lot of interesting objects: supernovas, pulsars, quasars, and regions in the vicinity of black holes. The space telescope in the visual range, together with the infrared telescopes, may enable us to discover planets of Jupiter's size in the stars nearest our sun. The point is that space astronomy is about to place us in a situation similar to Galileo's introduction of the telescope. In his day, it amounted to the invention of a new sense. In ours, it is as if we had been prisoners in Plato's cave: able to see only shadows, to view little and dimly. Now we can move into a universe of immense richness that may force us to change our views of the world most profoundly. What space offers us, then, is one of the most extraordinary opportunities in our history to challenge our communal perception of the universe. The future may never forgive us the consequences of failing to rise to the challenge.

The changing panorama of problems and opportunities that science brings about is the result of our attempt to satisfy our intellectual curiousity and our sense of adventure. And here we find the link between space science and exploration: sometimes one requires the other and, in any event, both are cut from the same cloth. But the same result illuminates another very important aspect of the nature of science: the satisfaction of scientific curiosity seems to have adaptive value. This result in turn offers the possibility of explaining several aspects of science, including the sense of exploration and perhaps even scientific creativity, in terms of a human nature firmly rooted in biology.

In this connection it is worth pointing out that curiosity has adaptive value in animals. Of course not all animals have curiosity, but those that do—say the Norway rat or the raven—can adapt to a great variety of environments or to a changing environment. Curiosity, most often in the spirit of play, leads them to obtain knowledge of the environment in which they find themselves. Curiosity is thus the key to their flexibility ("specialists in nonspecialization," Konrad Lorenz calls them), and their flexibility is the key to their adaptive success. We must also remember that the structures underlying intelligence are biological. As a result, Jean Piaget says that intelligence is "the most highly developed form of mental adaptation . . . the indispensible instrument for interaction between the subject and the universe when the scope of this interaction goes beyond immediate and momentary contacts to achieve far-reaching and stable relations."[5]

In short, intelligence has adaptive value. But science is not only a product of intelligence: it is also a means by which intelligence conceives of the universe, as we have seen. In such a case, should not science be expected to have adaptive value as well? Many of the lines of argument developed in this paper should testify in favor of this claim (e.g., the relation between theoretical achievement and the realization of opportunity or of danger). It must be kept in mind, however, that not all our faculties were selected for their present uses. There is no suggestion here that brains were selected for atomic physics or to build space telescopes. The selective forces had long done their job before humans thought of atoms or rockets. Nonetheless, this consideration does not prevent a faculty developed for something else to acquire adaptive value of its own. And in the case of science this connection is even closer than that.

Some would object to this sort of talk on the grounds that scientists often work with no applications in mind, nor do they accept or reject scientific theories on that basis. Nevertheless, the lack of such awareness (or even unconscious intention) cannot detract from the adaptive value of scientific curiosity anymore than it would in the case of the animals that are "specialists in non-specialization." The matter is to be settled in terms raised previously. Besides, it would be too simpleminded to expect that all scientific work should aim at dealing directly with the environment. Much of it is devoted to the mathematical, theoretical, and/or experimental articulation of scientific ideas (thus in my view it aims at dealing indirectly with the environment). And much other work attempts the integration of experience into a network that can then be applied (e.g., Neo-Darwinism).[6]

On the positive side of the claim about adaptive value, we must consider the results that should be expected from the satisfaction of our scientific curiosity, particularly as it is exercised through space science. They are as follows: (1) Being able to deal more easily with our environment—this is just what the land, communication, and other kinds of satellites have already done; (2) increasing the number and diversity of environments with which we can deal—consider, for instance, landing on other planets, surviving in hitherto hostile interplanetary space, and living in man-made environments; (3) coping with a changing environment—this is precisely the sort of thing that our exploration of the magnetosphere has permitted us to do (e.g., the discovery of solar wind with which the magnetosphere interacts to initiate the complex process of energizing the atmosphere from above.

All the results subsumed under these categories also help us to realize the complex nature of our environment as well as its relationship to others. Not going into space would prove disastrous eventually, for we need to understand better the way in which earth is part of a much larger environment. Even though we are barely scratching the surface, space has given us important discoveries (e.g., the magnetosphere and solar wind, and also tools to examine the possibly critical functions of the ozone layer). Comparative planetology has the potential to give us fundamental insights about our weather and plate tectonics. Finding out about the evolution of our solar system and its planets may not be a matter of interest only to idle dreamers—it may well prove of vital importance for the human race and their home planet.

Even these remarks do not capture the urgency of the matter. Whether in the next century we endure the great collapse that has been predicted in extrapolations of recent trends in the growth of population, industry, use of resources, pollution, and so on, the fact of the matter is that we face an uncertain future. What we decide to do may have massive repercussions. This makes it imperative that we try to understand the global environment far better than we do. But we cannot wait. The next century will be crucial, and it is almost here.

If scientific curiosity has adaptive value, and I have advanced reasons for holding that at least in the case of space science it does, then the attempt to satisfy it is in itself wise. Having adaptive value provides obvious advantages. Such attempt is also the expression of a natural function not characteristically embodied so much in problem-solving as in play. In our case, it is associated with wonder, with excitement, with adventure. This is the heart of space exploration.

Notes

[1] I have attempted such full treatment in a book in progress, *The Dimming of Starlight: The Justification and Philosophy of Space Exploration*. Some passages in this paper are excerpts from that book.

[2] Jean Jacques Rousseau, "Discourse on the Sciences and the Arts," in *The First and Second Discourses*, St. Martin's Press, 1964, p. 38.

[3] See Feyerabend's *Against Method*,(1975) Kuhn's *The Structure of Scientific Revolutions*, (1970), and Imre Lakatos, *Philosophical Papers*, vols. 1 and 2 (1978).

[4] This theory is developed in my *Radical Knowledge: A Philosophical Inquiry into the Nature and Limits of Science*, Hackett, 1981. The biolgical theory of knowledge described in the text also comes from this book.

[5] J. Piaget, *Psychology of Intelligence*, Littlefield, Adams, 1966. Lorenz's views can be found in his *Studies in Animal Behavior*, Harvard University Press, 1971.

Science, Humanities, and Illusory Bridges

David Paxman

Like many who look for bridges over the gulf between science and the humanities, I was at first intrigued and satisfied by the pictures of the scientific side of the gulf in books like Bronowski's *The Origins of Knowledge and Imagination*, Pirsig's *Zen and the Art of Motorcyle Maintenance*, and, above all, Kuhn's *The Structure of Scientific Revolutions*. But now I would argue that any bridges based on these books cannot land firmly on the bank of scientific endeavor but leave us stranded midway.

To develop this argument, I would like to pursue three points that apply in some degree to all three books but especially to Kuhn's. First, although Kuhn undoubtedly helps us understand the history of science, he can be ignored in the actual conduct of science. Second, even in accounting for the history and structure of scientific activity, Kuhn fails to explain the nature of scientific progress and truth except by waffling between mechanistic and relativistic viewpoints. Third, Kuhn encounters these problems because his analytical framework cannot accommodate the categories of working science without violating its own internal consistency. These criticisms do not rule out bridges, but they do suggest that bridges must be truly common to both and not merely extensions of one side.

One hopes that a book such as Kuhn's will not only help us talk about science but also help scientists conduct their work and so lead to a better understanding of progress and scientific advance. Kuhn encourages these hopes when he tells us that his account is partially normative, that it "provides a legitimate basis for reiterated 'oughts' and 'shoulds'," and that it "has consequences for the way in which scientists should behave if their enterprise is to succeed" (207). Yet from my layman's point of view, scientists cannot afford to abandon their unenlightened attitudes. Ironically, it is scientific truth and progress that attract explainers such as Kuhn to interpret science and tell us why it appears so successful.

In the popular mind and in the textbooks of science, Kuhn finds a false model of science. It is presented as a connected, linear movement characterized by addition and accumulation of knowledge, rather than by radical shifts in assumptions about the structure of the world and the nature of questions and evidence. According to Kuhn, our picture distorts the history of science because it suppresses these radical differences and shows "scientists of earlier ages . . . as having worked upon the same set of fixed problems in accordance with the same set of fixed canons that the most recent revolution in scientific theory and method has made seem scientific" (138). "That is not the way a science develops" (140), says Kuhn. And I agree with him. But the nasty question I wish to ask is the one I jotted on the leaf of his book when I first read it. Suppose you change the image of science to incorporate paradigm shifts and crises and to eliminate truth as a criterion. Would scientists function better? Science has done quite well even when its practitioners held a supposedly false picture of its development. Indeed, Kuhn admits that the traditional scientific education has been "immensely effective" in training men and women not only for what Kuhn calls "normal science" or "puzzle-solving," but for "another task as well—the generation through normal science of significant crises" (165–166). Until there is something approaching a revolution in the working methods of science (highly unlikely), Kuhn's exposition does not seem to improve the manner in which scientists work.

The problem with Kuhn's theory is repeated in Bronowski's *The Origins of Knowledge and Imagination*. Bronowski reports that as he was delivering a lecture, Nobel Laureate Linus Pauling rose to challenge him.

"Tell me one operational way in which what you are saying would make me do science differently," Pauling demanded.

"No, we know no other way of doing science," Bronowski had to answer (85–86).

Unsatisfied, Pauling pressed on. "How should my practice as a scientist be changed by the fact that you tell me convincingly that mechanism is not the answer to the world as is it put together?"

"Not at all," answered Bronowski.

"O.K. Why should I care? Why bother me with all this abstruse stuff about how the world is really put together?"

Bronowski's answer merely side-stepped the issue: "Because the scientist is a complete person who can no more talk about chemistry without thinking about peace than he can talk about peace without talking about chemistry" (117–119).

Whether or not a scientist thinks of peace when he talks about chemistry I do not know, but Bronowski's reply is a letdown. Perhaps it contains the only stable link between the sciences and the humanities, but in it we can also see a lesson for those who tell scientists how they work: if you claim to understand the structure of the world better than the scientists, then be prepared to demonstrate your understanding.

Even as a historical account, Kuhn's book has difficulty explaining scientific progress. When he explains the limits to scientific objectivity, truth, and progress, he draws on subjectivism and relativism. Yet when he acknowledges the advance of scientific knowledge, he grants the mechanistic position. It is difficult to pin him down.

Kuhn's subjectivism emerges in his assertion that each scientist lives to a degree in a different world and applies the discipline in subtly different ways (193). The choices made between competing theories are not always made on objective grounds that can "command uniform assent" (186). Yet when Kuhn turns to the essential unity of perception imposed by science he says, "to say that the members of different groups may have different perceptions when confronted by the same stimuli is not to imply that they may have just any perceptions at all" (195). He is willing to concede that some are more useful than others:

> It is just because so very few ways of seeing will do that the ones that have withstood the tests of group use are worth transmitting from generation to generation. Equally, it is because they have been selected for their success over historic time that we must speak of the experience and knowledge of nature embedded in the stimulus-to-sensation route. (196)

Kuhn admits that *knowledge* may be the wrong word, since he can see as well as we that he is slipping into terms that would negate his original point (196). Kuhn seems to invite misinterpretation and wants to have it both ways in his reponses.

Kuhn also invites the charge of relativism. On the one hand, he compares proponents of different theories with different language-culture communities who may both be right but lack the ability to translate for one another. In other words, scientific theories may be equally valid but untranslatable because of differing categories and viewpoints. Yet, Kuhn later grants to science almost all that it usually claims: that it shows genuine progress in its theories, that later theories can be differentiated from earlier on the basis of their "accuracy of prediction, particularity of prediction, . . . and the number of problems solved," in addition to their "simplicity, scope, and compatibility" (206). One wants to ask how theories can be both equal and better or worse.

Yet, Kuhn does not believe that better theories give us "a better representation of what nature is really like" (206). Science progresses, but not towards truth. It evolves—but only away from beginnings (170). To Kuhn, science will develop as it confronts crisis, "ever learning, and never able to come to the knowledge of the truth." While I do not object to Kuhn's position per se, I do object when his account of scientific progress comes so close to embracing a stable, knowable universe that we have difficulty separating it from the popular image of science. And after all, do not current theories give us a better representation of nature than do those of the Greeks?

Now, why does Kuhn get into these difficulties? His problems are in part rhetorical and semantic. One need only define truth in a more modern sense to be able to grant science's claim to it. After all, if science cannot give us some sort of truth, what can? But Kuhn's problems arise primarily because he approaches science from a metaphysical position that is at odds with that of science itself.

In his book, *World Hypotheses*, Stephen C. Pepper explains that views of reality ultimately sort themselves into irreconcilable world hypotheses, each with its distinct "root metaphors." Science is primarily mechanistic, while Kuhn's view is what Pepper would call contextualism. Each view has its strengths, but each lacks categories to account for the other's data.

Pepper characterizes the contextualist viewpoint in this way: reality is always complex, always changing, and always produced by myriad, often unspecifiable strands or connections that give events their whole quality or meaning. The contextualist does not affirm that these reveal the structure of nature, for each event may be unique, and the strands that give them their quality are always changing. Nor can the structure of events be detected merely through examination of their constituent strands because events are more than the simple sum of their parts. Furthermore, there can be "no final or complete analysis of anything" (249). To the contextualist, "There are many equally revealing ways of analyzing an event, depending simply on what strands you follow from the event into its context. At each stage of your analysis . . . this choice of what strand to follow comes up again, and every strand is more or less relevant" (250). Furthermore, the prevailing schema of both participants and observers is included (267). There is no possibility of element analysis and of the ultimate structure that such analysis promises to reveal.

While the strength of the mechanist lies in discovering and demonstrating stable cause-effect relationships, the contextualist's comes, as we see in Kuhn, from conveying events in their integrity and wholeness. The mechanist tells us about nature; the contextualist tells us how people think about nature, though opinions are offered about nature as well. Contextualism helps to take into account the different meanings of an event according to what scheme we use in perceiving it. Thus Kuhn reveals superbly the anomalies and crises that confronted scientists and the changes that they had to make in their thinking and—yes, seeing—in order to continue their work. As a tool for the description of social, political, and intellectual history, it is unsurpassed as a worldview. But contextualism runs into trouble when it describes physical reality. In other words, it can describe anomaly but not the entities or qualities that represent anomaly to the scientist.

Contextualism can tell us different ways to analyze a biological event such as cell division, but it dare not imply that a stable structure underlies it. When confronted with such data, the contextualist will fall back to reassertion, as Kuhn does:

> Contextualism is constantly threatened with evidence for permanent structures in nature. It is constantly on the verge of falling back upon underlying mechanistic structures. . . .Its recourse in these emergencies is always to hurry back to the given event, and to emphasize the change and novelty that is immediately felt there, so that sometimes it seems to be headed for an utter skepticism. But it avoids this impasse by vigorously asserting the reality of the structure of the given event, the historic event as it actually goes on. The whole universe, it asserts, is such as this event is, whatever that is. (234-235)

This analysis explains why Kuhn cannot fully answer objections.

Kuhn's contextualism clearly operates in his impressive attempts to recapture the nature of revolutions as they occurred, in his view of paradigms or "schemes" as one of the causes of scientific revolutions, and in his implication that as old paradigms fall to new ones, mankind does not get closer to the truth of nature but simply arrives at more fragmented, albeit more workable, explanations. He ignores, as his viewpoint forces him to, the assumptions and methods of the working scientist. Even when asking the wrong questions, the scientist has assumed that nature has a structure and that it is at least in part discoverable.

Whether the scientist's assumptions are true, I do not know. But they have certainly worked to produce the most powerful example of progress in knowledge that humans can offer, and the scientist who asks with Linus Pauling, "How will your knowledge affect the way I do science?" will never get a satisfactory answer from Kuhn.

List of Works Cited

Bronowski, Jacob. *The Origins of Knowledge and Imagination.* New Haven: Yale University Press, 1978.

Kuhn, Thomas S. *The Structure of Scientific Revolutions.* 2nd ed. Chicago: University of Chicago Press, 1970.

Pepper, Stephen C. *World Hypotheses: A Study in Evidence.* Berkeley: University of California Press, 1942.

Toward a Definition of Creativity

Richard J. Penaskovic

Many scholars traditionally regard science as the realm of objective knowledge whereas the arts and humanities have to do with the realm of personal expression. Since the turn of the twentieth century, authority has belonged mainly to science and authenticity to art and the humanities. Where art has been the watchdog of the concreteness and particularities of experience, the sciences have become the judges of universal and abstract principles of explanation (Starr 27). I would observe that there exists merely a distinction between the sciences and the arts and humanities, one that dates only from the nineteenth century. This distinction has until the last decade been made into a chasm or gulf between the two. What I see happening today is an emphasis on the commonalities that exist between the humanities and the sciences, one to which this conference itself bears abundant witness.

Another way of conceiving the relationship between the sciences and the humanities is to say that they complement each other. Science deals with problems that are essentially soluble, whereas the humanities deal with questions that are not (Goldman 19). In other words, the sciences are concerned with questions of fact to which there exists one right answer, while the humanities deal with questions of value where multiple right answers exist. A question of fact may be this: What is the chemical composition of salt? Such a question has a clear answer, namely NaCl. A value question, on the other hand, admits of no single answer—for example, what is the meaning of love, or what does it mean to be human, or the theme of this conference, what does it mean to be creative?

It is difficult to get a firm foothold on the concept of creativity, which may be compared to a rock overgrown with tiny moss, a very slippery surface indeed. I might add that creativity should not be regarded as any rock but rather as a diamond, one that sparkles from many angles.

I want to consider five meanings for the term *creativity*. First, creativity may refer to the individual's potential for achievement. Second, one may speak of the act of creativity. Third, the word *creativity* may be applied to the intervening process by which the individual's behavior is directed toward a creative product. Fourth, one may speak of creativity in terms of the production or development of an idea or a thing. Fifth, creativity may have reference to the individual person as such.

In regard to creativity understood as the individual's potential for achievement, social scientists have devised psychological tests that highlight four variables—fluency, flexibility, originality, and elaboration. In short, research indicates that the creative individual tends to be a nonconformist with the ability to pursue creative ideas despite societal pressures to see things in the traditional way and to leave things as others have found them (Hare 157). An example may clarify matters. Many parents believe that at least one of their children is creative. Parents are always on the prowl looking for concrete and tangible signs that their child exhibits creativity in some particular area, be it in athletic ability, intellectual prowess, or in music and art.

Creativity may also be understood in terms of a specific act—for example, Frank Lloyd Wright's creation of the Winslow House with its strong horizontals. When it was completed in 1893 in the Chicago suburb of River Forest, the Winslow House was indeed startling.

The psychologist Jerome Bruner looks at creativity in terms of a specific act. Bruner speaks of creativity as "an act that produces effective surprise." The word *surprise* refers to the unexpected that strikes one with wonder and astonishment. When they occur, "effective surprises" have the quality of obviousness to them. Bruner argues that a surprise requires both unexpectedness and interest, that is to say, that the surprise has a relation to some enterprise in one's life. Only those who are knowledgeable in a particular area are able to be surprised by effective surprises. Preparation and study are needed to distinguish trivial improbability from effective surprise. For Bruner, all forms of effective surprise result from combinatorial activity, which involves placing things in new perspectives. On this particular point, Bruner was influenced by Poincaré's *Science and Hypothesis* (1905), which speaks of making combinations that reveal unexpected kinship between facts long known but falsely thought to be unrelated to each other. In the final analysis, to create means to make useful combinations, observes Bruner. In making useful combinations, one orders the elements in such a way as to see relationships and groupings heretofore absent (5).

One may also speak of creativity *as a process*. As a process, creativity may be defined in various ways depending on the respective discipline that is involved. Ronald Alexander, for example, defines creativity as the process by which new information about the world is obtained through the methods dependent upon models not previously in use (natural science), or as the process by which insight or disclosure is provided humans about their condition or destiny (philosophy, social sciences), or as the process that issues sensual products, which provoke the aesthetic capacity of persons (the arts) (56). One may also look at creativity as a process in education as Lefrançois does. He calls creativity that special quality in students that teachers in other classrooms stifle. Other teachers are authoritarian, dry, humorless, rigid, rule-bound, and sober. There are certain factors that inhibit creativity, such as pressures to conform, rigid teacher personality, the use of ridicule and sarcasm, and other factors that tend to promote creativity in students such as encouraging self-initiated learning, developing a tolerance for new ideas, encouraging the manipulation of ideas and objects, and giving students information about the creative process (244).

Traditionally, the creative process has four main parts: (1) the preparation period, a time of intense preoccupation with a problem; (2) the incubation period, a time of unconscious work; (3) the illumination period, a stage in which the new idea emerges almost by itself; and (4) verification, a time of testing and revising one's hypotheses and communicating the results to others. E. P. Torrance describes creativity as "the process of becoming sensitive to problems, deficiences, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty; searching for solutions, making guesses or formulating hypotheses about the deficiences; testing and retesting these hypotheses and possibly modifying them; and finally communicating the results." Alicia Pagano argues that this definition has value because it stresses the factors affecting growth and provides researchers an observational framework for measuring creativity within a shared historical structure (129).

On the other hand, Vaune Ainsworth-Land maintains that there is no one creative process but proposes instead an integrating framework for understanding it. She distinguishes four levels. (1) Creativity of the first order is based on creation out of necessity, as when a child learns new words. (2) Creativity of the second order involves seeking improvement or modification of an existing idea, object, behavior, or pattern. Analysis, evaluation, and goal-direction describe the second-order imaging process, which is usually closely bound to the ego. In second-order creativity, one manages to leave a personal mark on the product, inasmuch as one realizes the self as a separate being. The product reflects its maker and the creative agent takes great pride in the actual creation. (3) When one has used up improvement, and modifications have been made, then third-order creativity is called for. Combination and synthesis characterize this form of creation. The end-result or the product may be called novel, containing as much new material as the old. (4) Fourth-order creativity involves the ultimate form of relatedness, which is absolute consciousness. Mystics are on this level when their identity merges with the Transcendent, as, for instance, in Hinduism when the *Atman* or authentic self becomes completely conscious of the *Brahman* or absolute consciousness so that *moksha* or liberation occurs.

Another model for understanding the creative process has been set forth by Kurt Motamedi, who delineates seven passages that embody the creative effort: (1) framing, which organizes a meaning for the pursuer but also organizes involvement; (2) probing, in which one scans for more information about the stimulus—this helps assess the potential risks and rewards of further exploration; (3) exploring, which leads to the formulation of a working hypothesis and the attempt to implement a tentative strategy; (4) revelating, as the work of exploration continues, and applying the new insights until an end is achieved; (5) affirming, which begins with an intensive examination of the discovery, its reliability and validity; (6) reframing, in which the relationship between the pursuer and the phenomenon tends to refreeze within the range of discovery; and (7) realizing, in which the new discovery must now be shared by going public with one's newly acquired idea, insight, or discovery (Motamedi 81).

I would observe that language tends to break down when one tries to speak of creativity as a process. One may argue that a creative process differs from a non-creative one insofar as the causal connections are not known in advance, as they are in those processes whereby the initial stage is itself explicable. As F. E. Sparshoot notes, the model of a process resembles digestion: one can identify beginning and final stages, and both enumerate and explain the steps whereby the beginning is transformed into the end (63).

One may take the act of writing a poem as an example of the difficulty of describing a process. Writing poetry is a creative process insofar as there is a movement from unclarity to clarity. Inchoate feelings are given some kind of structure. However, this is not simply a passage from beginning to end, but the arrival at an absolute beginning. The act of writing a poem is and is not a process. It is a process because the writer goes from unclarity to clarity; it is not a process because the end has the status of an absolute beginning in the light of which earlier phases are of little or of no account. They are completely transcended.

In sum, the creative process is a paradox. One does not find, as Sparshoot observes, an initial message to be encoded and transmitted (65). In fact, the message cannot be distinguished from the noise. On the one hand, the creative process is necessarily indeterminate. On the other hand, it must be strongly ordered and structured inasmuch as the end is ordered. Part of the problem has to do with the fact that in the process of composition, poets constantly make changes. An essential part of writing a poem, then, involves rewriting it.

One may also speak of creativity *as a product*. Here one emphasizes the production or development of an idea or a thing. Some scholars do not believe that creativity as such can be described but only recognized by what it produces. In the area of the arts, creativity means the creation of any new model for experience, resulting in something new but appropriate. Many researchers understand creativity as the ability to produce something novel. Gilchrist, for example, writes that all definitions of creativity have one essential ingredient, namely, the capacity to make new and valuable products (99).

There are four properties associated with a creative product: (1) unusualness, which refers to its place in a subset of a class of products—for instance, the essays of an undergraduate in theology should be compared with the essays of other undergraduates rather than with those of graduate students or college instructors; (2) appropriateness, which involves the relationship of a product to its setting or use—one needs a balance between appropriateness and what is odd or unusual; (3) transformation, which refers to the creation of new forms and/or new perspectives; and (4) condensation, which may be regarded as the combination of two extremes such as simplicity and complexity. An example of this would be the drawings of Matisse, which combine the complexity of psychological content with simplicity of line. At each viewing, such works are perceived in a new way, just as the poems of T. S. Eliot are interpreted differently by different readers, or as the words of Scripture are uniquely applied to the spiritual life of the individual.

Almost all definitions of creativity as a product share this one characteristic: they have to do with bringing something new into being. I would agree with Carl Hausman that creativity occurs on condition that a new and valuable intelligibility comes into being. In this regard, three terms need elucidation: *newness, valuable*, and *intelligibility*.

Newness exists only where something differs from its past. Coulson makes the point that all innovators bring something out of the past, at present neglected, and show how it enables one to live more fully in the present, and how identity continues in the face of change (132). John Henry Newman, for instance, returned to the Church Fathers in order to initiate a renewal of nineteenth-century Anglican spirituality and theology. One could argue that every activity or occasion is unique and therefore new. Thus, all things are creative. However, I would maintain that to extend the concept of creativity in such a way does not advance our understanding of creativity. It does not help us get at the meaning of a more special or striking kind of creativity.

To speak of creation as unique is to make a value judgement. Uniqueness by itself does not make for a creative product. One must also look at the term *valuable* when talking about the newness of a creative product, otherwise there is no difference between a new and creative art work and an imitation. As Hausman puts it, the outcome must be new in the sense of being different as an intelligibility. Hausman calls this Novelty Proper. He writes: "This is to say that the outcome is novel or new in the proper sense of newness, not in the sense of newness in its lowest common denominator, as a condition universally present in things, but in the sense that is expected when an outcome is regarded as a creation in the radical sense" (241).

To speak of a product as being valuable brings up the difficulty that judgments about value change. When Karl Rahner wrote *Geist in Welt*, it was turned down as a valid interpretation of Thomistic epistemology. Later scholars have hailed it as an epoch-making work. I would say that whenever an outcome is regarded as a creation, it must be looked upon as manifesting at least inherent value, that is, it must exhibit structure that is intelligible in some respect and be inherently valuable (Hausman 244).

The final term to be discussed is *intelligibility*. Some creative products have a radical and intelligible newness. The thing regarded as intelligible is an integration of elements, an ordered cluster whose identity is seen in a complex of coherent features. This identity is manifest in a "structure" that is unique and individual, yet simultaneously unfamiliar in that it differs from prior structures. This is what I mean when I speak of intelligibility in reference to creative products. Coherence, order, and structure all go together in speaking of creative products (Hausman 242).

Creativity may also be applied to *the person as such*. Hence one finds a plethora of studies dealing with the creative person. These studies are mainly psychological in nature. The literature on creativity shows that creative persons exhibit many common personality and biographical traits. These traits exist independently of the area of creativeness (Davis and Rimm 56). Creative persons possess at least a number of these personality traits. Creative persons are independent, self-confident, adventuresome, and curious; they also have a high energy level, are attracted to complexity, possess an above-average sense of humor, and are intuitive. Barron argues that creative persons are also highly motivated (246).

The preconditions necessary for creativity to flourish have also been studied. These include (1) highly developed mental skills so that the information previously acquired may be put together in a new way; (2) breadth and depth of knowledge (Mary Henle speaks of this in terms of immersion in one's subject matter—it seems to be the case that an unprepared mind is not likely to be a fertile environment for the flourishing of intuition.); (3) intense personal involvement with and commitment to the problem: creative thinking does not occur in regard to problems about which the thinker is lukewarm—rather, creative persons have a passion for what they do; (4) the ability to get lost in the here and now (Cannon 68).

Abraham Maslow believes that certain prerequisites of creativeness have something to do with this ability to become timeless, selfless, outside of history, society, and space. Both creativity and the peak experience have this in common: they involve getting lost in the present. Maslow sees this phenomenon as a diluted, more secular version of the mystical experience, described as a loss of self or as self-transcendence or egolessness.

Maslow asks whether the concept of creativeness and the concept of the self-actualizing, fully human person are one and the same. If they are identical, this would explain the fact that it is so difficult to define creativity. Creativity has something to do with the human person whose nature is mysterious or paradoxical. I would observe that one has the greatest scope for creative thinking in relationship to one's life. Mary Henle puts it well when she says that our own life is a subject "in which each of us is steeped, one in which we have access to information available to no one else" (48).

We act creatively all the time, thinking up ways to overcome the barriers that prevent us from reaching our goals. The way to develop inner resources is to meditate upon one's own life. Such meditation provides us with countless ways to be creative. I would argue that Maslow is correct in seeing creativity as a quality or *gestalt* of the whole person. Creativity is systemic, hence one can be creative in any discipline, from technology to taxi driving to physics (Maslow 69).

List of Works Cited

Ainsworth-Land, Vaune. "Imaging and Creativity: An Integrating Perspective," *Journal of Creative Behavior* 16 (1982).

Alexander, Ronald. "Theology as Creativity," *Dialog* 19 (1980).

Barron, Frank. *Creativity and Personal Freedom*. New York: Van Nostrand, 1968.

Bruner, Jerome S. "The Conditions of Creativity," *Contemporary Approaches to Creative Thinking*. Eds E. Gruber et al. New York: Atherton, 1963.

Cannon, Walter Bradford. "The Role of Hunches in Scientific Thought." *The Creativity Question*. Eds. Albert Rothenberg and Carl R. Hausman. Durham, NC: Duke University Press, 1976.

Coulson, John. *Religion and Imagination: In Aid of a Grammar of Assent*. Oxford: Clarendon, 1981.

Davis, Gary A. and Sylvia Rimm. "Group Inventory for Finding Interests (GIFF) I and II: Instruments for Identifying Creative Potential in the Junior and Senior High School." *Journal of Creative Behavior* 16 (1982).

Gilchrist, Margaret. *The Psychology of Creativity*. Carlton, Victoria: Melbourne University, 1973.

Goldman, James A. "The Restoration of Quality to Originality." *Humanities* 12 (1976).

Hare, A. Paul. *Creativity in Small Groups*. Beverly Hills, CA, 1982.

Hausman, Carl R. "Criterion of Creativity," *Philosophical and Phenomenological Research* 40 (1979):

Henle, Mary. "The Birth and Death of Ideas." *Contemporary Approaches to Creative Thinking*. Eds. Howard E. Gruber et al. New York: Atherton, 1962.

Lefrancois, G. R. *Psychology for Teaching*. 2nd ed. Belmont,CA: Wadsworth, 1975.

Maslow, Abraham. *The Farther Reaches of Human Nature*. New York: Viking, 1971.

Motamedi, Kurt. "Extending the Concept of Creativity," *Journal of Creative Behavior* 16(1982).

Pagano, Alicia. "Learning and Creativity," *Journal of Creative Behavior* 16 (1979).

Sparshoot, F. E. "Every Horse Has a Mouth: A Personal Poetics." *The Concept of Creativity in Science and Art*. Eds. Denis Dutton and Michael Krausz. The Hague: Martinus Nijhoff, 1981.

Starr, Paul. Rev. of *Sociology as an Art Form* by Robert Nisbet. *The New York Times Book Review*, 31 Oct. 1976, p. 27.

Keynote Address

The Imagination in Action

Leon Edel

I have probably been invited to speak to you because I have devoted many years to writing lives of creative individuals, men and women. This has meant exploring their origin, their heredity, their inner nature, their personalities, their "conditioning"—all the forces that led them into the expression, in various ways and forms, of their imaginings. The creative impulse is a powerful impulse; yet geniuses can give very little account of their genius; and the biographical surveyor and map maker faces constant vagueness and considerable *lacunae*. The well-springs of creation remain invisible. One is reduced to induction and surmise. Approximate truths and constant conjecture walk hand in hand.

I have found that in dealing with these problems I am concerned with the human imagination—that ambivalent part of ourselves that strikes out brilliantly into the fantastic as well as the real, and at the same time is capable of conjuring up torments and disasters. The imagination of disaster, Henry James called it, and it is nothing more nor less than human anxiety. The rare individual who doesn't experience anxiety is not usually a genius: such a person is more likely to be a psychopath. It is normal for us to have anxieties; it is not normal, and sometimes may be pathological, for us to suffer from constant and ominous compulsion and fear.

Imagination functions best when it is performing the act of conquering anxiety, when it enters into the creative action and by this means circumvents depression and a sense of futility, and in moments of serenity is capable of being decisive: it is then that it best leaps into the unknown, or makes combinations of disparate sensory and material experiences to arrive at a novel synthesis or fusion. If you tell me I speak in gross subjectivities, my answer can only be, yes, indeed—and these are the essences of artistic and scientific inquiries and creativities.

Creation is the imagination in action. We can discuss such action in reasonably concrete and even scientific terms. But when we attempt to touch the stuff of imagination we deal in mysteries and strange, often indescribable, forces—the magic of association is attended by unearthly divinities; at times we have a sense of dealing with the occult. What else does the word *inspiration* suggest? This may be why the Greeks invented extra-human creatures to preside, under Apollo himself, as our muses

© Leon Edel 1985

of inspiration and artistic performance. Imagination at its height is a moment of thought and connection, a fusing of disparate emotions and energies accompanied by an enormous sense of excitement and release; we partake of flashes of lightning not unlike those of the human sexual act, that cherished pleasure so intense and driving that it seems to propel us—as Freud insisted—through our greatest acts of life.

Because I believe in the human order of life, and the processes of living, I have a feeling that all we can say about the imagination and creation is in reality a paradigm for the act of love, the supreme act—that coupling of male and female that assures the continuity of the race: the fusion of sperm and ovum creates a new life, equipped normally with human physicality and human sensory feeling in its state of evolution and growth; it is completed not only at adulthood, but in all subsequent stages leading in the end to the fulfillment of existence and death. If we accept the paradigm, it is possible to speak constructively of creation in the arts and sciences, and to recognize that they operate under a human law, a kind of supremacy of cause and effect. That is creativity. The imagination belongs to that other sphere, the sphere that precedes creation. The imagination is the act of believing and loving, of wooing, of coupling, a coupling of many forms. The strategy of courtship belongs to the animal kingdom as well: one has only to observe the animals in pursuit of mating to see that they too proceed with an intensity and fever that resembles the intensities of the human order. But they obey instincts: humans often creatively disobey. Sometimes the act of the imagination fails; there is rejection, there is mis-mating, there are accidents. We see a process of trial and error. And even such seemingly mechanical procedures as artifical insemination, on whatever level, are preceded by imaginative scientific and physical phases.

Let me not labor this parallel. I think, as I speak, of a rare moment of creation and emotion in the life of Jean Jacques Rousseau, which he describes in a letter to Chrétian Malesherbes, one of his admirers (Green 95-99). In it he told of his greatest moment of illumination when he conceived his celebrated hypothesis that all men are born free and equal—that it is society that robs them of freedom and equality. A daring and magnificent hypothesis—we still feel its effects. Anarchism was founded upon it. It inspired revolutions. Yet it remains a poorly tested hypothesis, given DNA and other scientific advances in our time. Unequal genes, unequal brains; but equality at the ballot box—when such is provided—and before the law, when there is justice. In his letter, Rousseau tells how he set out one day to walk to Vincennes where his friend Diderot was imprisoned. As he walked, Rousseau read a newspaper and in his usual strolling way, with his mind wandering freely, he suddenly saw a paragraph announcing an essay contest arranged by one of France's academies. The subject was corollary to our subject today—whether the arts and sciences had purged or corrupted civilization. From the moment he saw this paragraph, Rousseau found his mind grappling with stupendous ideas: the few words acted as a trigger to a kind of inner explosion. We must go by his account, there is no other; he was suddenly overcome by a powerful sensation that he was touching eternal truth. I can liken what happened only to the moment of orgasm. He wrote: "Suddenly I felt my mind dazzled by a thousand flashes of enlightenment; swarms of vivid ideas presented themselves to me with a force and confusion which threw me into a state of indescribable turmoil! I felt overcome by a giddiness resembling intoxication."

What Rousseau is describing is a great moment of the imagination. It doesn't matter, and serves us little to ask, whether he is making it up or not: whether he really had this idea in this way, or only had it when he was describing it in his letter: the point is that it originated within him, within his mind and his emotions. If it was a fiction it was a very beautiful fiction and certainly a very imaginative one, for he went on to describe the effects quite as if a sexual act had taken place. There was a series of moments of amnesia: and when he recovered his rational mind, he found himself lying beside the road, under a tree. Tears were streaming down his face; his shirt was soaked with the salt water bath it had received.

All this is to be found in Rousseau's extraordinary letter to Malesherbes. It was written thirteen years after the stroll to Vincennes. "Oh! Sir," wrote Rousseau, "had I been able to write down a quarter of what I saw and felt under that tree, how clearly would I have shown up all the contradictions of the social system; how forcibly would I have exposed all the abuses of our institutions; with what simplicity I would have demonstrated that man is good naturally and that it is by their institutions alone that men become wicked."

Historians have wondered about the accuracy of Rousseau's memory and to what extent his account to Malesherbes may have been a dream-like fantasy. To a critic imbued, as I am, with the nature of dream this has less importance than the emotional content. Individuals undergoing psychoanalysis have on occasion boasted to me how they fooled their analysts by inventing a few dreams during long hours of anxiety-provoking silence. They little realized that an invented dream is an act of their imagination and quite as useful to the analyst as any other part of their verbal evocations. Rousseau's account is a description of his emotion and his imagination: there was a meeting of distinct items in the orgasmic moment he celebrated. He says to himself: look at society, it is bad, filled with evil and deceit and tyranny; look at the newborn babe, chaste and virginal, about to be bombarded by this antagonistic and coercive society. We can see in Rousseau's flight into liberty and equality how the idea of the noble savage arose in the minds of the Europeans—the idea that savages in their wild state were uncontaminated by the high civilization of the enlightenment and the residuals of feudalism. Perhaps they did not have the example of the Hawaiian islands, where the *alii* had their society, which Rousseau would have rebelled against quite as much as he did against the societies of the civilized. We may be sure that Rousseau's epochal tear-bath was not evoked by the simple title of the essay contest—the call for an essay on the effect of the arts and sciences on civilization. What Rousseau's mind and emotions heard was the corruption of the human entity by social contract and social evils; and we predicate that what was occurring within Rousseau was a flood of memories of his own struggle with human institutions as against his simplistic romanticism; his instincts had been unduly subjugated and he cried to be free, to have the liberty of the American Indian roaming the unfurnished continent. And so he spoke for the innate goodness of men and women, his own sense of his own innate goodness and the quarrel of his own purities with the treacheries of the world.

These moments of inspiration, of insight, of imagination, of clairvoyance—of sharp and clear seeing—have deep emotional strength. They are intimately known to those who have embarked on scientific experiments or have suddenly, on the literary side, seen them arise in fusions of poetry and narrative, in documents and texts, when disconnected ideas and feelings acquire the subtlest kinds of connections, connections that take place mysteriously in our inner selves to form a new wholeness. James Joyce described, or tried to describe this in his *Portrait of the Artist as a Young Man*, using Shelley's formulation of the moment when the mind is like a glowing coal (241-245). *Integritas, consonantia, claritas*—he was deep into the doctrines of St. Thomas Aquinas. Sometimes these moments of *claritas* may seem when described like small potatoes, but I have always vibrated and tingled in my own memories of this kind of moment. I experienced such a moment when I was eighteen. It remains unforgettable. I was in late adolescence, discovering the richness and wonder of reading. I had the freedom of the stacks in the college library and experienced a profound excitement, as if all the secrets of life were opening up for me. My imagination had been fired by reading the stream of consciousness passages in Joyce's *Ulysses*, in a copy smuggled from France, for it was then a banned book. One of my professors had suggested that I might look at the works of Henry James as one of

Joyce's significant predecessors. I found an entire tier in the stacks devoted to James, just then ten years dead; and as I dipped into these volumes, mystified by so rich a use of language, I found myself fascinated by mention that between 1890 and 1895 James had stopped writing novels and tried to write plays—but had been a wretched failure. Then he resumed writing novels and brought into being the most complex fictions ever written.

The critics[1] who told me this also lamented James's wasting five years on bad plays when he could have gone on writing good novels. I did not have Rousseau's orgasmic moment, but my mind began to tingle; a lot of little bells rang along my spine. What if James had applied his playwriting experiences, the experience of his failure, to the writing of *The Ambassadors* or *The Spoils of Poynton* or *The Golden Bowl?* I shuddered with delight at the thought of cause and effect. I spent several days reading all available books to discover whether anyone else had had this idea. No one had. Everyone dismissed the playwriting. James himself had been very secretive about it: he felt it was a sordid adventure for a man of letters to have to put up with mercenary managers and exhibitionistic actors and actresses. The hypothesis continued to thrill me. James had been, I said to myself, a novelist turned playwright. Could it be that in the end he was a playwright—even though a bad one—turned novelist again? carrying into the pages of his fiction the secrets he had learned?

As you see, to a scientist this might be small potatoes. But it had a delicious taste to my unformed self. When it came time to choose a doctoral subject at the Sorbonne, I chose James's "dramatic years." The Sorbonne, long before American universities, had a chair devoted to American studies. After a lot of research and talks with actors and dramatists who had known James—Bernard Shaw and Harley Granville Barker among others—and months in the newspaper reading room of the British Museum at Colindale trying to unearth the precise details of each failed play, I defended my dissertation[2] in the Salle Louis Liard before an august jury of French specialists in English and American literature. The jury knew little about James, and couldn't be as enthusiastic as I was, but grudgingly agreed that I had fulfilled the requirements of the degree.

I can hear the scientific members of this audience saying that my hypothesis remains a hypothesis, even though I had shown the dramatic structure of the later novels. All novels contain elements of drama. All novels use dialogue. I had convinced myself, and my published dissertation would convince a few others. But like thousands of dissertations, and my accompanying tingles of the spine, my discovery remained a conjecture. I went on to other work and other studies. At some point, about five years after taking my degree, the James family gave me access to Henry James's papers, then still in their possession. I was allowed to rummage among vast quantities of letters and to look in trunks that appeared never to have been opened after Henry James's death. At the bottom of one such trunk, amid typescripts of the failed plays, I found a batch of old scribblers containing Jamesian notes—some of them dated—in which, as he said, he was taking blank sheets of paper into his confidence. I found outlines of stories and plays in his big scrawl, invocations to his muse and the mysteries of his imagination, passages such as

> All life is—at my age, with all one's artistic soul the record of it—in one's pocket, as it were . . . Try everything, do everything, render everything—be an artist, be distinguished, to the last . . . I have only to live and to work, to look and to feel, to *gather*, to note. My *cadres* are all there, continue, ah, continue, to fill them.

These goadings of the self into confidence and purpose illuminate his often dry pages of mechanical workings out of plots. And then I came on the passages describing his defeat in the theatre, and suddenly the following:

> Has a part of all this wasted passion and squandered time (of the last five years) been simply the precious lesson taught me in that roundabout and devious, that cruelly expensive way *of the singular value for a narrative plan too* of the (I don't know what adequately to call it) divine principle of the scenario . . . a key that working in the same *general* way fits the complicated chambers *of both* the dramatic and the narrative lock?
>
> (*Notebooks*, 105–106, 187–188).

I was eighteen again. The bells were ringing once more along my spine: and Henry James was saying, very elegantly and symbolically, what I had discerned in my immature youth. His posthumous words had validated my old hypothesis and in language that reminds me of the sperm and the ovum. The key that fits "in the same general way" the complicated chambers of drama and narrative—I am ready to be accused of being very Freudian, but even without Freud, the key and the lock in our time, and after our sexual revolution, eloquently speak of the creative act as well as the perpetuation of the race.

I hope I have demonstrated to you some small part of the way in which our imagination works: of how constructive we can be. The imaginations of literature or the arts, the imaginations of love and of disaster, the anxieties and triumphs of our bringing together moments of insight and perception, resemble the moments in science when chemicals mix and explode or physical laws are juggled in impressive formulae involving mass, weight, velocity, and the speed of light—I offer you the typical jumble of a non-scientific person. We know too that once the imagination takes its leap, whether to small potatoes or earth-shaking (and earth-destroying) discovery, there follows a great deal of donkey work—my apologies to the helpful donkey! Who can say how many years of inner ferment and drudgery lit up Rousseau's lightning stroke on the road to Vincennes? I think at this moment of the donkey work Pierre and Marie Curie carried out for seemingly endless days, melting down tons of pitchblende in order to extract a tiny bit of dangerous radium. My researches at Colindale were quite like melting down pitchblende: my quest was for evidence that might explain my illumination. James had written in his notebook after his remarks about the key and the lock, "I almost hold my breath with suspense as I try to formulate it"—and the *it* was, he said, "a portentous little discovery." So it had been for me. And James also wondered whether he was exaggerating the importance of this "little discovery," its magicality. I have heard scientists describe the same kind of magicality, and I often think in this respect of Fleming's coming on penicillin when he found the moulds destroying bacteria.

The late Lord Snow—C.P. Snow–attempted to approach our subject of today in the 1950s in his Cambridge lecture on "The Two Cultures and the Scientific Revolution" (14 et seq). He was disturbed that those of us on the literary and non-scientific side of the creative fence did not possess the language of science. His basic claim was that science had become so complex that it was impossible for governments to legislate without possessing the requisite knowledge. But in making this point, Lord Snow compared the thrill he got in pondering and knowing the second law of thermodynamics with the thrills he experienced in reading Shakespeare. When he asked literary critics, they did not know the second law. "Yet," he said, "I was asking the scientific equivalent of: Have you read a work of Shakespeare?" I believe that Snow, himself a formed but not wholly dedicated scientist and an amateur novelist, did not perceive that there are wide differences between comprehension and emotion: that the heart of his problem resides in language. Literary folk, being ignorant of mathematics and the language of the laboratory, experience little emotion when they read the second law or other physical laws. But the universal language of Shakespeare, in spite of the complexities of Elizabethan usage, conveys powerful emotion to anyone who knows the English language. The real relation between Snow's "two cultures" resides in the imagination of discovery; and the problem for both the scientist and the artist is that they find and make on such a high level of discovery that the literalists—and they are in the majority—simply do not understand what their flight into the unknown means. Genius, creation, imagination has to put up with people of lesser genius, lesser imagination, who write book reviews, or report on science, or discuss and admire, but simply do not have the requisite creative insight, the great élan that remains so private and is most often incommunicable. How can a soaring imagination cope with common pedantry? how can a soaring poet face the babble of the critics? not to speak of the flatfooted individuals who, like Wordsworth's Peter Bell, simply call a spade a spade. Shakespeare understood this

> Tell me where is Fancy bred
> Or in the heart or in the head
> How begot, how nourished?
> (*Merchant of Venice* III.i.63)

And he might have added to Lord Snow the second law of thermodynamics belongs to the language of the head, is a superb performance of the rational, and doesn't partake of the spectrum or rainbow of the irrational. In using the word *begot* Shakespeare sustains our paradigm—fancy leads him to the human act of procreation.

In writing the lives of men and women I have found that the new psychology—that is the psychoanalytical psychology of Freud and his successors—has greatly enlarged our understanding of the universality of the imagination, its mischievous ambiguities and its action in the creative process. We all imagine things. The negative imagination tries and succeeds in frightening us with the imagination of disaster. The positive imagination sets us day-dreaming about divans and dancing girls, palaces, privileges, miracles, and wonders. It is a great source of fiction in the form of wishful thinking; among scientists hypotheses often express fiction before they become fact. That is why science has so rigidly pursued evidence and proof. Psychological evidence, whether in a physical gesture or in our use of words, in our dreams or our behavior, often reveals secrets: but we tend to be inattentive to this kind of evidence (*Stuff of Sleep and Dreams* 22-43).

What did Freud do to further our understanding of the imagination? His greatest contribution was to make us aware of the unconscious and to demonstrate the truths that lie within the fantastic in our dreams—truths we refuse to tell ourselves during our waking hours. He showed us how a slip of the tongue or of the pen is often a truth we were concealing from ourselves. Harry Stack Sullivan, adapting Freud, spoke of "selective inattention"—our tendency not to see or hear what is disagreeable to us (Perry 166, 236, 305–306). The recent American election showed how a great part of this television-fixated nation prefers role-playing and fiction to the hard facts of government. We are by nature self-deceivers. Our imagination, which tries constantly to lead us astray, also provides us with a wide-ranging ability to grasp at all that we mythologize and beneficently understands the human capacity for metamorphosis. Psychoanalytical psychology distinguishes between the imagined unreal and the real, and helps keep us on guard against self-delusion and paranoia. Advertising long ago tuned into human self-deception. The language of advertising is spread thick across our lives: it is a kind of euphemism that has been changing our language in significant ways by a display and reinforcement of half-truths. Undertakers have become morticians; elderly persons have become senior citizens; street cleaners and garbagemen become sanitation squads. We can all testify to the obfuscating process. We have all seen television commercials that associate in our minds the frenetic behavior of drunkenness with bubbling soft drinks. The euphemisms are designed to make us "feel good." Advertising knows the nation's oral and anal needs. It is quite as effective as propaganda in totalitarian states. Who has not sung a commercial in the shower? The instruments we create can be horrendous as well as benign. The language of the unconscious is extremely important for the understanding of any form of creativity.

We have metaphors of disease and illness as well, and the language of the unconscious creates them. There is a relation between illness and creativity: it has been the subject of some of the most striking works of the imagination of our time—as those who have read Thoman Mann's *The Magic Mountain* know. The biographer reads the language of pathology or disease in the writings of genius. We have studied literature as if it were an intellectual process untouched by emotion. The reverse is true. It is an emotional process that is constantly being rationalized. I have demonstrated in my book *Stuff of Sleep and Dreams* and other writings how depression colors every creative life, and its phases are reflected in the life-pattern and the life-work.[3] The romantics used to call it melancholy; and Benjamin Rush, the inspired physician who was a signer of the Declaration of Independence, called it *tristimania*. We know that none of us escape it—and usually the most euphoric individuals often seek compensation for their chronic blues. Different stages of life have their depressions; the depressions of aging or youth are marked among all of us and notably among writers, for they give voice to it. We need no test-tube science to observe this and to see it written out in poetry, in Keats or Whitman, or in music in the long, sad, and depth-shaking slow movements of Mozart or Beethoven; or in many passages of even so stolid-seeming a citizen as Johann Sebastian Bach, the least mercurial of geniuses. Creation siphons off stored aggressive feelings that have found no outlet, grievances that have had no escape, the hidden hatreds of the heart. Even before Freud, William James and Bergson demonstrated how we are great repositories of undischarged feelings. The civilization Jean Jacques Rousseau blamed for our troubles does indeed put barriers in front of our primitive instincts and our imagination of disaster; it does breed our anxieties. The writer, the composer, the painter, siphons off such stresses in a kind of creativity of self-therapy that brings release. Small wonder that Kafka spoke of writing as being a form of prayer—both supplication and fulfillment. But like the sexual drive, or the hunger drive, we move from release to stress, from fulfillment to further need: as vessels of wrath empty themselves they are inevitably filled up again. If the frustrations and stresses are extreme, we get desperate measures. Two notable examples in our time are those of T. S. Eliot who reduced his abulia by writing "The Waste Land" and Virginia Woolf, who after many years of manic depression—and some forty-five books—finally achieved her suicide.

Some scientists or their researchers shrug off the unconscious as something we can't taste, or smell, or touch, or perceive. They insist upon the palpable and the material. It is true: the unconscious is perceived only through the shadows it casts, the data it projects; we study it by induction. But its data are abundant. I usually reply to such scientists—"And your atom? I have never tasted, knowingly touched, smelled or seen an atom, or a quasar, or a quark" (and the quark exists as a joke in the pages of James Joyce, probably one of his derivations from the snark). Is it not a matter for wonder that the great discoveries of our time belong to the invisible?—testimony indeed to the remarkable creative energy lodged in the human imagination, its ability to pick up signs and wonders and discover hidden patterns and deduce the unknown from the known. The imagination proceeds from fiction to truth, or from truth to fiction—and we must be on constant guard against its wonderful fantasies and learn how to use them—from hypothesis to demystification. I am certain that the greatest discoveries of science—those that have diminished disease and may decrease poverty and suffering, which are supposed to banish rage and war, will go on creating their Frankensteins as well. Life is a constant mixture of good and evil—fertilizers that provide more food poison us, sprays are health-giving and destructive of animal life, radiation heals and destroys.

Empirical evidence and scientific evidence, deduction and induction, walk hand in hand: our proof may not be absolute but we often have clouds of witnesses. Artists differ from scientists in the forms they use, which are distinctive and invariably related to their different senses—the plasticity of the painter, the verbal memory of the writer, the ear of the musician. In science it is above all the eye and reason, the presence of the deductive and formulating mind, with the senses as auxiliaries. Each medium has its message. But the model for both is human sexuality.

"If I have seen farther, it is by standing on the shoulders of giants," Newton said. He was implying another of his laws, an unwritten law—that giants beget giants, that genius creates genius. So too creation becomes procreation, procreation engenders creation: I offer this, if no one else has named it, as Edel's axiom.

Those of us who have lesser imaginations—and there are all kinds—can't climb to the shoulders of giants. So we sit on their knees. That may be called talent. And those who cannot climb to their knees have imagination of a more mundane form. Yet each individual is king or queen of a particular personal creative domain. The question is not one of democracy; it is one of degree and scope. To be sure there are persons who can imagine nothing. We may condescend and call them flat-footed, but their literalness is also helpful. They are the ones who can on occasion tell us whether the emperor has his clothes.

Notes

[1] In particular Olive Elton, *Modern Studies* (1907); Ford Madox Hueffer, *Henry James* (1916); Dixon Scott, *Men of Letters* (1916); Helen and Wilson Follett, *Some Modern Novelists* (1918); Percy Lubbock, *The Craft of Fiction* (1921); and Van Wyck Brooks, *The Pilgrimage of Henry James* (1925).

[2] Leon Edel, *Henry James: les années dramatiques* (1931). See also Leon Edel, ed., *The Complete Plays of Henry James* (1949).

[3] See especially the essays, "Tristimania," "Abulia and the Journey to Lausanne," "The Madness of Virginia Woolf," and "A Cave of One's Own," in *Stuff of Sleep and Dreams*.

List of Works Cited

Edel, Leon. *Stuff of Sleep and Dreams*. New York: Harper and Row; London: Chatto and Windus, 1982.

Green, F. C. *Jean Jacques Rousseau*. Cambridge: Cambridge University Press, 1955.

James, Henry. *Notebooks*. F. O. Mattheison and K. B. Murdock, eds. New York and London: Oxford University Press, 1947.

Joyce, James. *A Portrait of the Artist as a Young Man*. New edition. London: Jonathan Cape, 1924.

Merton, Robert. *On the Shoulders of Giants.* New York: Harcourt Brace, Jovanovich, 1965 (new edition 1985).

Snow, Charles Percy. The Rede Lecture, Cambridge University Press, 1959.

Perry, Helen Swick. *Psychiatrist of America: The Life of Harry Stack Sullivan.* Cambridge, Mass.: Harvard University Press, 1982.

Keynote Address

The Genesis of Atomic Physics and the Biography of Ideas

Arthur I. Miller

A clue to deeper insights into the connection between scientific thinking and the origins of scientific concepts is an observation made by scientists such as Albert Einstein and Henri Poincaré, whose research led them to probe the process of thinking itself—namely, that "scientific thought is a development of pre-scientific thought" (Einstein 1934). Some psychologists, particularly Jean Piaget, reached a similar conclusion. A fundamental thesis of Piaget's genetic epistemology is that the evolving structures in scientific thought parallel structures in the formative psychological processes in children. Inspired in large part by Piaget's writings, I approached these fundamental problems by using the results from case studies in the history of science as data for theories of cognitive pyschology in my book, *Imagery in Scientific Thought: Creating Twentieth-Century Physics*. Our understanding of the invention of atomic physics is incomplete without trying to unlock the black box in which stimuli are transformed into responses—that is, to explore creative thinking itself. A valuable clue for proceeding is to assume that there is a connection between pre-scientific and scientific thought.

Children construct knowledge by actively incorporating perceptions into schemes and then adjusting the schemes to fit the situation—that is, by the assimilation-accommodation process. According to genetic epistemology, we attempt to come to grips with nature by means of this same process, which leads to a hierarchy of increasingly better approximations to physical reality, with each level richer than the one below.

Piaget divides the development of representative activity into three stages: sensorimotor, egocentric representative, and operational. At the end of the sensorimotor period there are fleeting pictures of sensory objects. The egocentric representative stage is divided into two parts: preconceptual thought and intuitive thought. Preconceptual thought begins with the construction of object permanency, signalling the start of semiotic functions. The dependence on imagery during

© Arthur I. Miller 1986

preconceptual thought decreases during the transition to intuitive thought. In the concrete operational stage, operations possess full reversibility and are internalized, but thinking is still somewhat dependent on imagery. In the formal operational stage, the transition from picture to image to symbol is completed, and reasoning with images is much deemphasized.

Needless to say, when Bohr and Heisenberg began their research they had entered the formal operations stage of thinking years before. Clearly, extensions of certain notions from genetic epistemology are required for historical research. I suggest the following:

(1) The construction of knowledge by children and physicists is not exactly the same. By means of the assimilation-accommodation process, the child's schemes develop the mathematical and physical attributes of the levels of genetic epistemology that are the child's version of physical reality. Physicists deal with schemes that possess *ab initio* the proper mathematical attributes to operate.

(2) A theory's interpretation of new data places the theory into a lower level of genetic epistemology.

(3) A second definition of assimiliation is required: the application of a scheme to problems involving empirical data, data from thought experiments, or aesthetic-philosophical commitments.

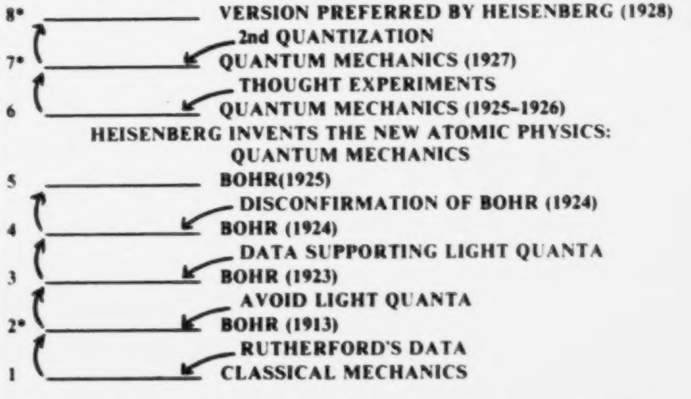
(4) With Piaget, I define *structure* as the set of possible states and transformations of which the system that actually pertains is a special case (1970b). Here I propose that the relevant equilibriated structures are the various formulations of Bohr's atomic physics during 1913–1927, the permanent object, reversibility, conservation, and systematization. The states or systems are the wave and particle modes of matter and light. The transformations are based on the mathematical notions in use during the particular period of theory development. I turn next to the genesis of atomic physics.

In 1911, Ernest Rutherford used classical mechanics to analyze data from the scattering of alpha-particles off thin metal foils. Rutherford concluded that the atom was a miniscule solar system with a positively charged nucleus and planetary electrons. He was unable to explain this using classical physics because the revolving planetary electrons radiate energy and eventually spiral into the nucelus. A classical solar system is unstable, but most atoms are stable or else we would not be sitting here!

In 1913, Bohr incorporated atomic stability into a theory in which by axiom there is a lowest orbit beyond which a planetary electron cannot fall. A second axiom is that only certain orbits are permitted. While in one of these allowed orbits, the electron does not radiate any energy. Bohr referred to these allowed orbits metaphorically as "waiting places" (Bohr 1913). The planetary electron's downward transition between allowed orbits results in the emission of light. Although the drastically altered classical mechanics could still be used to calculate allowed orbits, it could not trace the electron's transition. Consequently, in transit the electron cannot be visualized; it appears and disappears like the smile of the Cheshire Cat.

We may describe these developments as follows (see levels 1 and 2 in figure 1). Rutherford assimilated the scheme of classical mechanics to his 1911 data with no attempt at adjustment. In 1913, Bohr adjusted or accommodated the disequilibrated version of atomic physics with its unstable atom to a new equilibrated structure, that is, the 1913 Bohr theory. Central to the 1913 Bohr theory is the permanence of the solar system atom. Consequently, at this juncture Bohr's theory displays representative activity analogous to egocentric representation. Rutherford's 1911 conception of the atom (the product of accommodation) is the signifier or image that represents the atom, but neither is it the atom itself nor is it the image of the scheme in Bohr's atomic theory because, as Bohr emphasized in 1913, the images from classical mechanics were imposed on the atomic theory through the perception-laden interpretation of the mathematical symbols of ordinary mechanics.

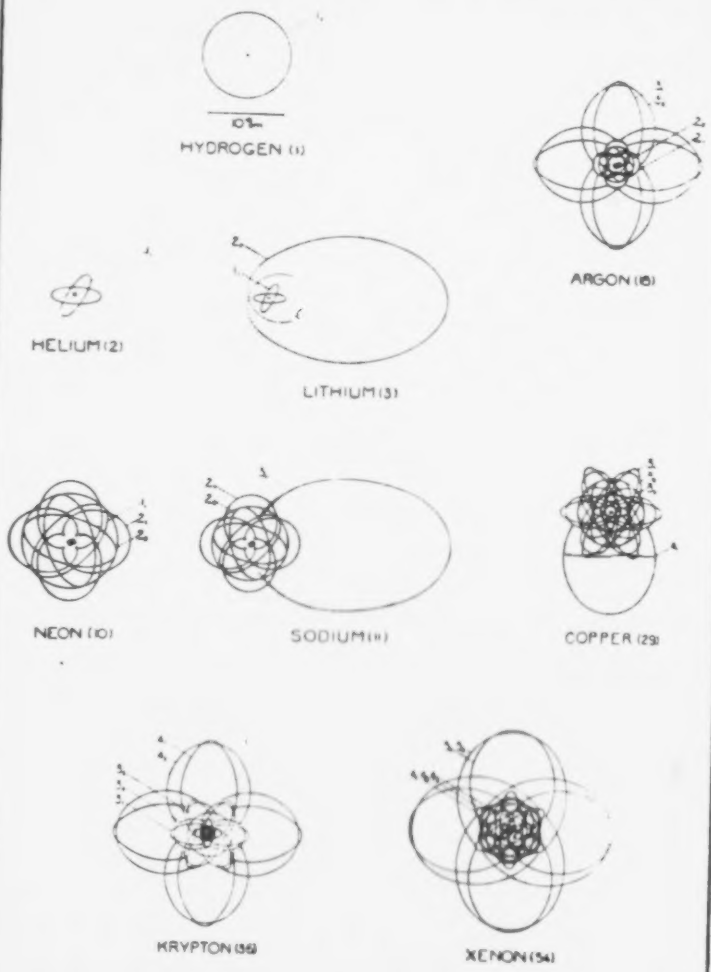
Figure 1: The Assimilation-Accommodation Process in the Dynamics of Atomic Physics, 1913–1928.


8* VERSION PREFERRED BY HEISENBERG (1928)
2nd QUANTIZATION
7* QUANTUM MECHANICS (1927)
THOUGHT EXPERIMENTS
6 QUANTUM MECHANICS (1925–1926)
HEISENBERG INVENTS THE NEW ATOMIC PHYSICS: QUANTUM MECHANICS
5 BOHR(1925)
DISCONFIRMATION OF BOHR (1924)
4 BOHR (1924)
DATA SUPPORTING LIGHT QUANTA
3 BOHR (1923)
AVOID LIGHT QUANTA
2* BOHR (1913)
RUTHERFORD'S DATA
1 CLASSICAL MECHANICS

*Object Permanence (level 2), systematization, conservation, and reversibility (level 7 for Bohr while Heisenberg constructed conservation in level 8).

From 1913 through 1923, atomic physics problems were analyzed with visualizable models of solar system atoms. For example, figure 2 illustrates atomic structures based on Bohr's atomic theory. Indeed, by

Figure 2: Atomic Structures based on Bohr's Atomic Theory


10⁻⁸cm
HYDROGEN (1)
ARGON (18)
HELIUM (2)
LITHIUM (3)
NEON (10)
SODIUM (11)
COPPER (29)
KRYPTON (36)
XENON (54)

1923 the Bohr theory had become a magnificent edifice, and figures such as this led some very prominent physicists to wax poetic. Max Born wrote (1923): "A remarkable and alluring result of Bohr's atomic theory is the demonstration that the atom is a small planetary system . . . the thought that the laws of macrocosmos in the small reflect the terrestrial world obviously exercises a great magic on mankind's mind; indeed its form is rooted in the superstition (as old as the history of thought) that the destiny of men could be read from the stars."

In 1923, however, the solar system image of the atom withered away principally because atoms did not respond to light as a solar system atom should. A possible solution was in Albert Einstein's light quantum. In Einstein's *annus mirabilis* of 1905, he proposed that to understand certain processes that involved the interaction of light and matter, it was helpful to assume that light propagated through space like a hail of shot or light quanta. Most major physicists, Bohr included, resisted the notion of light quanta because it was counterintuitive, that is counter to what Bohr and Heisenberg, among others, referred to as our "customary intuition," a characteristic style of visual thinking among many scientists and engineers trained in the German cultural milieu. The term *customary intuition* is rich in Kantian overtones. It is the mental imagery abstracted from phenomena that we have witnessed in the world of sense perceptions, and it is the imagery of classical physics. According to customary intuition, light is a wave phenomenon. For example, certain properties of light (like interference) are often explained by abstracting from properties of water waves. Then how can particulate light quanta produce interference? How can something be both wave and particle—that is, be both extended and localized? Light quanta were to be avoided right from the start in atomic physics. Bohr agreed.

In order to continue to exclude light quanta from atomic physics, Bohr folded into his theory in 1923 a mathematical formalism by which an atom's constituent electron reacted to an incident light wave as if the electron were represented by as many harmonic oscillators as there are atomic transitions. In this way, the characteristics of the scattered light wave could be correlated properly with the incident one. Although we may visualize an atomic oscillator to be a billiard-ball-like electron attached to a spring, there are so many possible transitions that a constituent electron is neither localized nor visualizable. Consequently, in the post-1923 Bohr atomic theory, the electron's image is no longer imposed on the theory by customary intuition but is given by the theory or scheme. According to genetic epistemology, during 1913–1923 the thinking of Bohr and most other physicists focused on visual models and so emphasized accommodation over assimilation—that is, a phase of thought that Piaget calls “imitation” (see levels 2 and 3 in figure 1). Moreover, since their thought was centered on light as a wave, their assimilation of data was incomplete. Similarly, accommodation was incomplete owing to its limitation to waves. These are the characteristics of preconceptual thinking. Decentering begins with the formation of a structure that is an image not of an object but of a scheme. This was the case with the assimilation of the 1913 theory to the requirement of avoiding light quanta. The resulting accommodation led to the 1923 oscillator version of Bohr’s theory in which a constituent electron was represented by a very large number of oscillators. The next portion of egocentric representation is what Piaget refers to as “intuitive thinking.”

Late in 1923, data became available that strongly implied the reality of light quanta. Bohr’s response was a physics of desperation. In 1924, he incorporated or assimilated these data into his atomic theory with accommodation to a level more abstract than before (see levels 3 and 4 in figure 1). In the 1924 Bohr theory, the oscillator representation of a bound electron is referred to as “virtual oscillators.” The virtual oscillators emitted waves that carried probabilities for atomic transitions, in addition to the usual quantities transmitted by radiation. Bohr included probability with its inherent discontinuity in place of light quanta. A stunning prediction was the nonconservation of energy and momentum in the individual atomic processes. To most everyone’s relief, in early 1925 this theory was proved wrong. In response to this disconfirmation, there was an accommodation of the 1924 Bohr theory to a sophisticated mathematical structure based on virtual oscillators that emitted only waves of radiation and not probability (see levels 4 and 5 in figure 1).

Nevertheless many physicists had yet to accept fully the light quantum’s reality, once again owing principally to its counterintuitiveness. Take, for example, the widely read paper on the interaction of light with atoms written in spring of 1925 by Heisenberg and the eminent physicist Hendrik Kramers. They mentioned light quanta, but treated light like a wave.

We may say now that the new 1925 scheme for the Bohr theory exhibits what Piaget calls intuitive thinking because the 1925 theory’s descriptive apparatus is given by the theory or scheme, and is semireversible because the theory assimilates data to only light as a wave. Disequilibrium in language (i.e. mathematical notation) serves even further to place the Kramers-Heisenberg paper and thus atomic physics in the intuitive-thinking stage. For example, Kramers and Heisenberg used the notation or language ν_e and ν_a for the frequency emitted and absorbed during an atomic transition, instead of notation such as ν_{ik} for a transition between atomic states i and k. The improper notations prevented them from realizing the deeper meaning of representing the atom by an ensemble of harmonic oscillators. As Heisenberg recalled, we "practically [had] the matrix multiplication."[1] Besides the spectre of light quanta, the 1925 Bohr theory was further discredited by the recently proposed wave-particle duality of matter for which data were accruing.

When last ditch efforts by Heisenberg to apply visual solar-system models had failed, he, more than anyone else, became convinced of the far-reaching advantages of renouncing visualization. In June 1925, he created the scheme or structure of a new atomic physics or quantum mechanics. At its basis was the virtual oscillator metaphor of the unvisualizable atom.

To some extent the birth of Heisenberg's invention of quantum mechanics squares with Piaget's definition of creativity—namely, the assimilation of a scheme to data for which the scheme was not originally meant. Briefly, while most everyone else was concerned over the *dynamics* of the interaction between atoms and light, Heisenberg alone realized that current problems were rooted in not understanding the atomic electron's *kinematics*. So Heisenberg assimilated a scheme that at first sight was not a direct response to the interplay between atoms and radiation. Among the scheme's ingredients was the virtual oscillator metaphor. Accommodation of this scheme led to the "unusual kinematics" that was the new atomic physics.

On the one hand, genetic epistemology helps us to understand the gradual transformation of knowledge exhibited in the hierarchy of structures in the Bohr theory from 1913–1925. On the other hand, genetic epistemology often fails to capture the nascent moment of creative thinking such as Heisenberg's invention of the new atomic physics. Some flexibility in structure formation is offered by "reflective abstraction," which is the unquantifiable process where reorganization of material from lower-level structures can lead to the formation of higher-level structures. But here I found useful Gestalt psychology's notion of an invariant or conserved quantity entering a disorganized field of knowledge to precipitate creativity. For example, Heisenberg's realization that the new peculiar mathematics of quantum mechanics agreed with conservation of energy. I turn next to sketch the remainder of the genetic epistemological scenario.

During the brief period mid-1925 through fall of 1927, problem after problem that had resisted treatment in the old Bohr theory was solved, and several exciting and unexpected results emerged. Some results were puzzling and misunderstood because until the fall of 1927 the new atomic physics lacked unambiguous interpretation of its syntax. For example, although results of calculations agreed with empirical data, neither the meaning of intermediate manipulations nor the newly emerging mysterious properties of subatomic particles were understood. This situation was rooted in the total failure of physicists to extend the mental imagery of classical physics, i.e., customary intuition with its perception-laden language, into the domain of the atom. Although renunciation of the customary intuition in the atomic realm had been a prerequisite for Heisenberg's invention of quantum mechanics in June 1925, we read in subsequent key papers by Heisenberg and Born, among others, the desire for some sort of visualization of atomic processes.

Physicists were adrift in the world of sense perceptions. But they had nothing else, and continued reliance on customary intuition was the stumbling block in Bohr's and Heisenberg's heroic struggles at Bohr's Institute in Copenhagen (fall of 1926 into 1927) to interpret the syntax of the new atomic physics. As Heisenberg wrote in an article of November 1926, "the electron and the atom possess not any degree of direct physical reality as the objects of daily experience." On 23 November, 1926, Heisenberg wrote to Wolfgang Pauli, "What the words 'wave' and 'corpuscle' mean we know not any more" (Pauli 1979). Heisenberg recalled that these struggles left Bohr and himself in a state of despair (1975). Indeed the psychologist Rudolf Arnheim, in his book, *Visual Thinking,* writes of the "apprehension" that develops in a scientist when the change is made to a "model of higher complexity [when] the timeless stability of concepts, cherished by the thinker, no longer has its counterpart in the world those concepts describe."

According to genetic epistemology, Bohr's and Heisenberg's assimilation of data from thought experiments that investigated paradoxes from the wave-particle duality was partial because it was centered on one or other scheme of matter, i.e., wave or particle, with no reversibility. Their accommodation was partial since an image of a wave or particle was evoked. Heisenberg's correspondence and published papers show that he persisted in focusing on the corpuscular mode of matter and the wave nature of light.

By February of 1927, the new mathematical methods enabled Heisenberg to achieve reversibility for the mathematical schemes of the quantum mechanics with its unvisualizable particles and a rival version of atomic physics that dealt with matter exclusively as waves—that is, a wave mechanics, with its accompanying imagery. Heisenberg resisted reversibility concerning the physical schemes of particle and wave. In his opinion, the wave mechanics did not discuss adequately the physical properties of matter behaving like waves. In this intuitive-thinking stage, Heisenberg was led to permit the mathematical formalism of the quantum mechanics to give restrictions on perception-based symbols for such as x for position and v for velocity—that is, he realized his famous uncertainty relations.

Unfortunately, historical data are too scarce to explain through genetic epistemology Bohr's acceptance in late 1926 of the complete reversibility between the wave and particle aspects of light and matter with conservation of physical properties. Bohr's full reversibility and conservation led him to the complementarity principle, which is a deeper result than the uncertainty principle. Bohr had realized that the paradoxes of the quantum theory were rooted in the wave-particle duality of light and matter. His genial response was to propose that at the underlying atomic level both horns of the dilemma are, in fact, connected. This "wavicle," to use a term of Arthur Stanley Eddington's (1927), is open to neither our perceptions nor our measuring instruments. That is, we can imagine or perceive only quantities that are either continuous or discontinuous but not both. According to complementarity, while the wave and particle states are mutually exclusive in an experimental arrangement, they are complementary because both are necessary to describe an atomic entity. In other words, depending on how you choose to measure an atomic entity, then that is what it is. For example, if the experimental arrangement is set up for wave phenomena, then the wave side or mode of the atomic entity is "observed," i.e., experimentally measured. There is also an essential difference between the pictures from customary intuition of how a system develops in space and time and the actual course or behavior of atomic phenomena. According to complementarity, the space-time pictures of customary intuition must be interpreted only as restricted metaphors.

Thus, the assimilation by Bohr and Heisenberg of the 1925–1926 structure of the quantum mechanics to their thought experiments resulted in accommodation to the 1927 structure (see levels 6 and 7 in figure 1). Bohr achieved reversibility and conservation. Systematization was constructed because the 1927 structure possesses the mathematical formulation and physical interpretation that we use today for nonrelativistic quantum mechanics.

However, in 1927 Heisenberg achieved only reversibility of mathematical schemes of the wave and quantum mechanics. The reason is that at first complementarity did not completely satisfy Heisenberg due in part to a conceptual-physical point—namely, how the discreteness of electric charge emerged from the electron's wave description. This problem was solved in 1927–1928 through the invention of a far-reaching mathematical prescription for transforming the wave and particle states of matter and light into one another while these two states remain mutually exclusive. This procedure became known as "second quantization." To Heisenberg, second quantization expressed the symmetry between wave and particle descriptions that was inherent in Bohr's complementarity principle, and thus in conservation too. This leads us to suggest that in 1928 Heisenberg assimilated the 1927 structure of the quantum mechanics as he understood it to the second quantization (see levels 7 and 8 in figure 1). The resulting accommodation was to the 1928 structure within which he achieved conservation.

In atomic physics, therefore, conservation transcends Piaget's theory of mental development. While the child realizes that a piece of clay maintains its amount of substance when it is rolled into longer pieces, in the atomic domain the electron maintains its charge, mass, momentum, wavelength, and spin, whether it is a particle or a wave, and whether these properties can be imagined.

The hierarchy of structures in figure 1 invites us to paraphrase Piaget's famous statement in *Biology and Knowledge* (1971) that "life is essentially autoregulation" as "science is essentially autoregulation." We have identified parallels between structures in genetic epistemology. Systematization is strikingly illustrated in Heisenberg's thinking. He continued to seek in the mathematical formulations of atomic physics total independence from customary intuition. It is noteworthy that in Heisenberg's case, conservation followed systematization. But a shortcoming in this genetic epistemological analysis is that throughout the genesis of atomic physics we find the longing of scientists for visualization of physical phenomena. In fact it turned out that Heisenberg restored imagery to atomic physics, in contrast to genetic epistemology's description of the formal operational period. A hallmark of a fruitful scientific theory in the twentieth century is some sort of mental imagery.

Applying the fundamental hypothesis of genetic epistemology to the genesis of a complex theory (in this case the new atomic physics) necessarily involves the hotly debated issue of going beyond formal operational thinking (e.g., see Commons et. al. 1984 and Miller 1987). For example, although the formal structure of relativity is mathematically the same as that of pre-relativistic electromagnetism, the meanings of the basic quantities such as space and time are different. Historical studies have revealed that these different meanings did not emerge in a strictly logical manner that can be explained by the INRC group of the formal operational stage. Even more striking is the case of atomic physics whose syntax (logic) and semantics (representation) differ strikingly from those of lower-level pre-quantum theories. In the genesis of both theories, extra-logical grist for the mill of assimilation was required from the scientist's environment. But this grist does not find its proper place in a theory that is rooted essentially in logic as is genetic epistemology.

We may thus widen the scope of genetic epistemology by proposing that it describes the dynamics of scientific progress as driven by the upward spiral of the assimilation-accommodation process. The result is a hierarchical series of structures in which equilibrium is achieved only in part. Is it not the case that the brain is an open system in search of equilibration, which the enquiring mind never achieves? If the level of formal operations is final, then there will be no scientific progress to theories whose logic is richer than either the classical logic of Piaget's formal operational level or the content of the previous lower-level theory. The mystery of creative scientific thinking is how richer structures or theories emerge from the less rich ones. Only interdisciplinary collaboration can yield an answer.

It is appropriate to conclude with an observation of Jean Piaget (1970a):

> A great deal of work remains to be done in order to clarify this fundamental process of intellectual creation, which is found at all levels of cognition, from those of earliest childhood to those culminating in the most remarkable of scientific inventions.

Notes

[1] From an interview with W. Heisenberg on 13 Feb. 1963 for the Archive for History of Quantum Physics.

List of Works Cited

Arnheim, Rudolf. *Visual Thinking*. Berkeley: University of California Press, 1971.

Bohr, Niels. "On the Spectrum of Hydrogen." Lecture delivered to the Physical Society of Copenhagen on 20 December 1913. Reprinted in N. Bohr, *The Theory of Spectra and Atomic Constitution*. Cambridge: Cambridge University Press, 1924.

Born, Max. "Quantentheorie and Storungsrechnung," *Die Naturwissenschaften* 27 (1923): 537–550.

Commons, M. L., F. A. Richards, and C. Armon (eds.). *Beyond Formal Operations: Late Adolescent Development and Adult Cognitive Development*. New York: Praeger, 1984.

Eddington, Arthur S. *The Nature of the Physical World*. Ann Arbor, Mich.: University of Michigan Press, 1968. (From Eddington's Gifford Lectures of January-March 1927).

Einstein, Albert. "The Problem of Space, Ether and the Field in Physics." Reprinted in A. Einstein, *Essays in Science*, pp. 61-77. New York: Philosophical Library, 1934.

Heisenberg, Werner. "Quantenmechanik." *Die Naturwissenschaften* 14 (1926): 899-894.

———. Discussion with Professor Werner Heisenberg, in O. Gingerich (ed.), *The Nature of Scientific Discovery: A Symposium Commemorating the 500th Anniversary of the Birth of Nicolaus Copernicus*. Washington, D.C.: Smithsonian Press, 1975, 556–573.

Kramers, Hendrick and Holst, H. *The Atom and the Bohr Theory of Its Structure*. Trans. R. B. and R. T. Lindsay. London: Gylendal, 1923.

Miller, Arthur I. *Imagery in Scientific Thought: Creating 20th-Century Physics*. Boston: Birkhauser, 1984.

———. "Imagery, Intuition and Strategy in Creative Scientific Thinking: Albert Einstein's Invention of the Special Theory of Relativity." To be published in H. E. Gruber and D. Wallace (eds.), *Case Studies in Creativity* (forthcoming 1987).

Pauli, Wolfgang. *Wissenschaftlicher Briefweschel mit Bohr, Einstein, Heisenberg, U. A.* A. Herman, K. V. Meyenn, and V. F. Weisskopf (eds.). Berlin: Springer-Verlag, 1979.

Piaget, Jean. *Play, Dreams and Imitation in Childhood*. Trans. C. Gategno and F. M. Hodgson. New York: Norton, 1979.

———. *Genetic Epistemology*. Trans. E. Duckworth. New York: Columbia University Press, 1970 (a).

———. *Structuralism*. Trans. C. Maschler. New York: Basic Books, 1970 (b).

———. *Biology and Knowledge*. Trans. B. Walsh. Chicago: University of Chicago Press, 1971.

Panel Topic

Educating for Creativity

The Science Place

Glenn Leto and Christopher Chiaverina

> It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of freedom; without this it goes to wreck and ruin without fail. It is a very grave mistake to think that the enjoyment of seeing and searching can be promoted by means of coercion and a sense of duty.
>
> —Albert Einstein

Science is the method we employ to perceive our environment. It is employed because it consistently, although not always, provides us with perception that faithfully represents reality. Science is a participatory experience by which the individual interacts with the phenomena being studied. A scientist, whether professional or not, is an explorer searching for new horizons. True exploration is a creative process during which new ideas evolve from pre-existing knowledge. Just as Cook and Cortez were guided by the voyages of Columbus, the explorer-scientist moves into new territory guided by the discoveries of his predecessors. Yet, because of the very nature of science, this experience is difficult to provide to students in the traditional classroom.

Currently, many individuals are intimidated by science, and the situation is so acute that science-anxiety classes have been established to deal with the problem. It is particularly important that this anxiety be addressed, otherwise students become the victims of their own fears. As Mallow and Greenburg (1983) point out, "these students create a self-fulfilling prophecy and do poorly in science; or they may avoid science at all costs to avoid the painful anxiety which they associate with it."

One of the ways to establish a positive attitude toward science and alleviate the anxiety is by presenting interactive exhibits in a nonthreatening environment. At Barrington High School in Barrington, Illinois, we created such a center in The Science Place. While fun is not the goal of science education, The Science Place gives the visitor the opportunity to explore science in an atmosphere that is less structured and more play-like than can be achieved in the traditional classroom.

Since its inception in 1981, the Science Place has given more than 10,000 visitors of all ages the opportunity to act as explorers in the world of natural phenomena.

The Science Place also provides the student and teacher with the props to generate concrete examples of scientific phenomena. Our exhibits provide these concrete examples, whether a visitor encounters live fish that appear to be made of glass or a giant swinging pendulum.

In creating The Science Place, we took as our model Frank Oppenheimer's San Francisco-based Exploratorium, the ultimate example of a science center. The Exploratorium provides numerous exhibits that demand the interaction of the observer, prompting thought, stimulating curiosity, and posing questions. This interaction leads to contemplation. Oppenheimer and his staff created the Exploratorium not only as a science center but also as a model to be used in the development of similar learning centers throughout the world. The Science Place, produced by high-school students, consists of sixty hands-on science exhibits that produce a much reduced but comparable experience.

The Science Place is an on-going project of Barrington High School's science club. We feel that this center provides a unique opportunity for our club members to gain experience solving problems creatively, and it has long been recognized that one of the best ways to increase personal understanding is by teaching others. The opportunity for learning in developing the exhibits is obvious, but we wanted our visitors to be involved. Club members took responsibility for developing the exhibits, but the exhibits themselves were to allow visitors freedom to explore. An ideal exhibit would be one that presented a simple demonstration of phenomena but with sufficient latitude to encourage investigation. The potential of a museum such as we planned lies in its ability to foster the freedom we wanted to encourage. This has been our guiding principle, and we list below the exhibits that we decided to include:

The *Polarized Light Table, Colored Shadows,* and *Newton's Cradle* provide examples of the type of exhibit that encourages development of concepts. When viewed on *The Polarized Light Table,* transparent materials shine in brilliant display of color. The exhibit provides a brief explanation and then allows the visitor to manipulate such variables as the type of material, orientation of polarization, and the nature of the light source. Younger visitors are particulary intrigued by the exhibit's potential for producing multi-colored artworks using cellophane tape as the medium.

Colored Shadows provides opportunity for the visitor to experiment with light. A student may initially be intrigued by the reality of three colored lamps that combine to cast white light on the wall. As the student steps between the lamp and the wall, he is often startled to discover that he casts a multitude of different colored shadows.

Five in-line bowling balls suspended by cables form *Newton's Cradle*. A familiar table-top toy was the inspiration for this large-scale device, which provides the visitor with the tools to explore momentum and energy. Usually without reading the directions, the visitor is enticed to lift a ball and release it to discover what will happen. After this initial contact, even the youngest begin to question why the intervening balls remain stationary while the outermost ball springs outward. This experience leads the visitor to try out different combinations of balls.

Not every exhibit can act as catalyst for exploration since the center as a whole must serve many purposes. Some, for example, may simply be an enjoyable experience, such as a work of art or a toy; others may communicate information that enhances other exhibits or simply instructs. Often these are limited by expense, space, time, and safety constraints. A number of our exhibits fall into this category.

Although *Everyone is You and Me* does not provide extensive opportunities for creative involvement, it does demonstrate scientific principles in an interactive and creative manner. Based on the laws of reflection, this simple exhibit is capable of producing startling results. Sitting on opposite ends of a plate of window glass, two participants adjust the intensity of spotlights shining on their faces. When just the right amount of reflected and transmitted light is achieved, one operator will observe an eerie composite of two faces. One visitor dubbed this "The Genetic Engineering Device."

While some of our exhibits are copies of works found in other museums, there is still ample opportunity for the student builder to become part of the creative process. Due to the financial, technological, and space limitation imposed on The Science Place, even faithful reproduction generally requires some degree of problem-solving.

Intrigued by the Exploratorium's *Gray Step* display, one of our students decided to reproduce it. *Gray Step* appears to consist of a large gray rectangle divided in half by a shaggy rope. When the rope is lifted, however, it become clear that there are two distinctly colored squares, one noticeably darker than the other. At first our student tried painting the squares by trying out various shades of gray. The result was failure. Just as he was about to give up, he struck on the idea of producing the shades of gray photographically. As a result of this, he came on seven adjacent gray steps rather than two, and he found that a dowel rod of any color, a pencil, or even a finger would obscure the boundary between two shades, making them indistinguishable.

After visiting the Exploratorium, another of our students was so impressed by the four-hundred pound *Resonant Pendulum* that he became obsessed with the idea of creating one himself. The problems inherent in building, much less supporting and transporting, such a massive device were obvious. How was he to create the pendulum bob? What could be used to support the four-hundred pound weight, since our ceilings clearly could not? And finally, how could the pendulum be transported? In probably one of the most clever and imaginative approaches we have ever witnessed during our involvement with The Science Place, our student arrived at a solution. He decided that the pendulum bob was to consist of four cylindrical concrete disks, supported by a steel core and base. This was to ensure ease of construction and of transportation. To support the pendulum, he designed and constructed a wooden structure strong enough for its task but also easily dismantled for transport. This student had little or no experience in carpentry, steel, or design skills. He sought expert advice when he needed to, but the design and construction were essentially his. The fact that the pendulum has now been in use for three years attests to his skills.

We feel that The Science Place has enriched the experiences of our own student designers, but more than that, it has also presented our school district with the unique opportunity to deal with student science-anxiety and provide concrete examples of what is taught as abstract concepts in the classroom. Each of our exhibits allows the visitor to delve into natural phenomena at a level appropriate to age. While many may be experiencing the phenomenon for the first time, the serious student also has the opportunity to experiment in a more sophisticated manner.

In addition to dealing with these two very important problems, The Science Place has permitted other faculty to use the museum as a resource for other disciplines. During the past two years, English, Art, and Technology faculty have found uses for it as a basis for speeches and creative writing. Technology students have undertaken to create additional exhibits, working from concept to demonstration. We are coming to recognize that The Science Place not only motivates the students but is also an exceptional resource for interdisciplinary interaction not only within the high school but between the various levels of the school district.

We feel that this "delicate little plant" comprised of the "holy curiosity of inquiry" can be nurtured within The Science Place. The sight and sounds of the museum draw the visitor into our mental amusement park, where the exhibits are not only touched but touch in return.

List of Works Cited

Mallow, J. V. and S. L. Greenburg, Science Anxiety and Science Learning, *The Physics Teacher*, 21 (1983) 2.

How Not to Teach People to Be Good Scientists

Peter T. Manicas

How does one teach people to be good scientists? The answer traditionally has held two parts. First, students should be taught something called "scientific method." Second, students must acquire substantive knowledge of the languages and achievements of the sciences. These go together when we insist that students take a lab science, or when they learn geometry in the tenth grade. The lab science serves, presumably, to give the student knowledge of the science and hands-on experience in "the experimental method." Because the language of mathematics is indissolubly part of the language of science, good scientists must be strong in mathematics to learn how a logical justification proceeds. Geometry is believed to do this.

Now I firmly believe that students should learn science and math. Indeed, if I had my way, they would get more, though not necessarily more of what they usually get. I can begin to make clear what I think is wrong with what we do by challenging the idea that there is such a thing as a scientific method that can be taught.

My criticism can be divided. In the first place, there is the question of what can be *taught* and what this means, and second, there is the easier question for me, whether there is anything that can reasonably be called "scientific method," if by that one means some orderly procedure or process distinctive to science. People do need to think and to reason, and inquiry must in some sense be controlled. But this is true wherever people are engaged in inquiry. For there to be a method, there must be rules, procedures, and established routines. Rational inquiry—good thinking and good reasoning—is not so codifiable. On the other hand, if one argues that science is distinguished by its mode of control, I would insist that no one ever very helpfully exposed what this really amounts to.

We used to think that we could easily distinguish the so-called "context of discovery" from the "context of justification." The context of discovery was not rule-governed. It was the creative part of science. But there is a logic to justification and accordingly the control of scientific inquiry answered to that logic. The ideas here are familiar enough, found in the first chapter of any introductory science textbook:

the ideas of hypotheses, evidence, and experimental test. Thus, we test a hypothesis by submitting it to an experiment that either confirms or falsifies the hypothesis. In science, accordingly, "facts" constitute the evidence that governs belief.

By now, two very critical problems with this view have been exposed. The older problem, less frequently noticed, is that we utterly lack an inductive logic adequate to say when evidence confirms or verifies a hypothesis (Popper rightly insists on this in *The Logic of Scientific Discovery*). Some "facts" do indeed seem to persuade the relevant scientific community, but their appeal cannot be understood in terms of logic. The other and not unrelated problem is even more serious. It holds that what counts as evidence is itself highly problematic. It is often said that there are no so-called theory-neutral facts to which one can appeal, that facts are only facts in terms of some theory that happens not to be under critical scrutiny at that moment. There is no foundation upon which to build the edifice of science.[1]

One of the consequences of this development has been to alter completely our understanding of the problem of justifying the assertions of science and so has made it very much less clear what it is that makes a branch of inquiry scientific.

Some knowledgeable writers, including Paul Feyerabend in *Against Method: An Outline of an Anarchistic Theory of Knowledge* (1975), have argued that science is at bottom irrational and different only in having an institutionalization different from that of other inquiries. But in my view, controlled inquiry is common to all rational inquiry.[2] Because rationality is not rule-governed, it does not follow that there is no difference between belief held rationally and belief held irrationally. Similarly, while it is true that the key differences between science and non-science are differences in institutional development, it is important to recognize that the sciences have different interests, problems, institutionalizations, and achievements.[3] While these points are surely crucial to a critical reassessment of scientific education and suggest that there ought to be serious regard for the distinct history of the science being taught, I must return to the problem of thinking and reasoning and what this means.

It is generally held that learning geometry provides discipline and instruction in systematic thinking. Now, while I do not believe that there is such a thing as a scientific method, the usual justification for teaching geometry is correct: if properly taught, learning geometry is a way to develop systematic reasoning power. The words, however, are carefully chosen: it is a way to *develop* systematic reasoning power. We cannot teach people to think or to be good reasoners, but we can put people into situations that stimulate powers requisite to heightened rationality.

Sadly, many of our efforts have been counter productive because we teachers have supposed that we can teach people how to think. As the author of a textbook in modern symbolic logic, I here speak with experience.

It is not easy to define *thinking*. Let us say that thinking makes reference to a very wide range of natural processes carried on by humans and almost certainly by animals of lower orders. Thinking is not identical with reasoning (or in older language, ratiocination), nor is it identical with reflection. Reasoning is problem-solving, construing that broadly. Reflection is conscious examination, play, and contemplation of the contents of mind. Reflection is often a conversation with oneself and may have all sorts of aims: idle daydreaming, perplexed cogitation, reasoning. Thinking, however, is not necessarily conscious; we do not need to be aware of thinking processes. Some examples of the words that we use to identify these processes will help here. "Abstracting," "getting an idea," "seeing a connection," "passing from insight to insight"—each name "thinkings." We know that we do these, but—and this is important—neither we nor sophisticated empirical psychology has anything but the vaguest idea of how we do them.

We do have some very general and important ideas about this. Jerome Bruner says that human cognitive capacities "cannot be understood without reference to the enabling powers of culture and the heritage of man's evolution as a primate" (6). As organisms we have the potential to be thinkers, our brain and central nervous system give us the power to learn. At the same time human cognitive capacities develop only in culture, among language-using cultural beings. But what is almost entirely lacking, Bruner points out, is some plausible account of how we do this. Consider a most primary thinking capacity, indispensable to any learning—the power of abstraction. After a recent review of currently available theories, the psychologists David Kelley and Janet Kreuger conclude:

> The theories we have analyzed seem to exhaust the current possibilities . . . the deficit here is not one of detail, which might be rectified by further research along established lines. It is a failure to address the essential issue: how is it that we can come to see the world of determinate, particular objects, which is given in [commonsense] perception, in terms of abstract concepts whose processed contents—abstract properties, and abstract, uniform kinds—do not seem to correspond to anything in the external world? None of the theories offers any promise, even in principle, of answering this question. (59)[4]

The implications of this lack are serious. It is often said that we must be inductive learning machines of some sort if we are to take inputs from the external world, process them, survive, and then convert them into the more esoteric activities of science, literature, and art. But this means that every newborn is creative in becoming a socialized human! Not only do we lack an understanding of so-called creative thinking, but we lack an understanding of the most rudimentary and widely shared powers of thinking. If so, then, just as we are impotent to give instruction in creative thinking so too we cannot offer a logic for ordinary thinking.

It might be objected that everyone probably knows this, and perhaps no one ever supposed that they could teach people to think if teaching is something like what one does if one teaches someone biochemistry or how to drive a car. There would be truth to this objection however much present practices so often suggest the opposite. Good child-rearing practices, supported by good developmental psychology would make the distinction I mentioned earlier. What one can do is to provide situations that stimulate, encourage, and develop powers of thought—or at the very least—avoid structuring development so as to inhibit that development.

What then of reasoning and logic? We know what logic is taken to be. It refers to the science of good reasoning. It gives one the rules of sound inference. It provides us with the criteria of good reasoning and sound argument and with a tool to be employed in reasoning and argument.

There is little doubt that we do reason, just as we think. As I said, we can think of reasoning as problem-solving, where this is construed very widely. We reason when doing science, we reason when we need to make a decision, we reason when we seek agreement with others, we reason when we read, since the text may contain arguments and we must, if we are to understand it, follow the argument—identify the conclusions and the reasons given for it. Reasoning, then, surely involves thinking and when reflective, it is a kind of disciplined thinking.

But there is no science of good reasoning. The logician can provide no rules whose mastery can make people good or better reasoners. Reasoning is wider than any of the rules that can be articulated. Like thinking, and because it does involve it, it too is a creative process not bound by rules.

Two sorts of cases may be distinguished. In the first, we can think of reasoning as the active process of creating or constructing a reasoned argument, so often the focus of the professional logician. Logic is not needed here; instead, knowledge and the capacity to think are required. You have to know something to see some connection that can then be represented in a language, you have to have a body of pertinent belief to suggest generalizations and hypotheses, and you have to have a keenly developed capacity to abstract creatively to provide pertinent analogies, illuminating metaphors, and significant connections. The powers of mind need materials. Making good reasoners in this sense, then, means developing thinking, as I have argued above. But it also means giving people materials with which they can reason. Putting the matter crudely, we all have the capacity to think, to get ideas, and to see connections and the like, but to put this capacity to work in reasoning, we must also know something. Indeed, the more we know, the better we can reason.

It is possible to reason about nothing. The full machinery of modern deductive logic and a sophisticated computer are available to assist this. But computation is not reasoning, however much there are computational moves in reasoning. The point can be clarified by considering the second type of case. Here we have an argument. Our problem as reasoners is to follow and assess it. Now most arguments are not at all like the abstracted, rarefied types found in logic textbooks. Most arguments are full of irrelevances, gaps, redudancies, negotiable ambiguities, confusions, and sometimes even inconsistencies. I am not applauding this and would, with my logical colleagues, urge improvement. My purpose, however, is fully served with a neat, rarefied example: the hypothetical syllogism.

If the interest rate rises, aggregate investment will fall.
The interest rate is rising.
Hence, aggregate investment will fall.

Logicians will tell you that this argument is impeccable, a deduction; the conclusion not only follows from the premises, it follows necessarily.

Now reasoning does involve deductive inference—what in a computer is called "computability." I said earlier that reasoning is wider than any of the rules that can be articulated. We can now say that reasoning is not to be identified with deduction, a form of inference for which rules can be articulated. No logician would deny this, yet I do not think that the implications of this are always clear.

In the first place, while a logician could provide an elaborate argument that our argument is valid (i.e., when the premises are true, the conclusion is true), at some point he would have to appeal to your *intuition* if he were to convince you. Let me save you the time of rehearsing the logician's argument and appeal to your intuition right now: Do you "see" that in this argument, if the premises are true, the conclusion must be true? Of course, by appealing to your intuition I am right back into the area of thinking, about which so little is understood.

As Bruner notes, we are not any nearer "to an explanation of a child's solution to a problem to say that the solution presupposes some kind of grasp of the principles of logical implication" (3)—the principle that I asked your intuition to confirm. Indeed, that puts the cart before the horse. The principle of logical implication is itself an abstraction made by us to identify what for us is a psychologically compelling move in reasoning. Reasoning came first, a natural process carried on by successful organisms in transacting with their environments. Logicians then asked, can we abstract some principles involved in this mysterious process? As now is clear, all the so-called "rules of inference"—what used to be called the "laws of thought"—are only variations, extensions, and alternative forms of the abstraction we called "the principle of logical implication." No one memorizes them with the idea of becoming a good thinker. I am not saying that the sophisticated apparatus of modern formal logic is not useful. But it should not be identified with reasoning or with thinking.

The problem is obvious. We must assess the truth of the "if . . . then" sentence that is the major premise of the argument. We are back now where we were a few pages ago. Now we need knowledge, just as the creator of the argument needed it. You must be able to see a connection between moving interest rates and investment, to have a quite complicated set of ideas—a theory—about the mechanisms of a capitalist economy. The point is more general, however. Less sophisticated reasoners reasoning about less esoteric problems need to be able to see a connection between morality and humanness, between food and satisfaction. Just because these connections are widely available and constitute what is part of a common store of knowledge should not blind us to their role in reasoning, however much that reasoning is directed at the more rudimentary aspects of our human practices. We rightly think of the creative thinker as making some new or unnoticed or undiscovered connection.

I have argued that neither thinking nor reasoning is governed by rules of which we have any understanding and that therefore we can't teach people how to think or reason. Yet there are implications of this analysis that suggest what we can do. Let me end with some of these.

(1) If the analysis is on the right track, then methods-orientations, especially ones in which students are given rules, will likely be counter productive. Geometry is a good example. One can pass geometry in most schools without doing any serious thinking, not to mention reasoning. The already good thinkers will, likely, not be stopped by poor pedagogy. Quite on their own, they will make the necessary abstractions, generalize the context-bound strategies, and get the idea.

They will wonder why others collapse when the exercise is a little different.

(2) If thinking and reasoning are constrained by lack of knowledge, if people with no experience and no information cannot think or reason in a vacuum, then we must assure that our curricula are rich in content and we must, if we are to avoid pseudo-reasoning, tap those cognitive resources that our students already have.

The first point is obvious, the second can be clarified some by shifting examples. Two gifted teachers of writing, Marie Ponsot and Rosemary Dean, have pointed out that you cannot teach a class in writing without a subject. Writing, which is a kind of objectified reasoning, needs content:

> . . . if we remain in our composition class, a class in writing without a subject, and ask a student to write a less 'personal' and more general essay she cannot follow this procedure. She cannot generalize, because she does not have the knowledge. Though she cannot generalize, she can formulate in language a generalization. Of course, the generalization is empty because there is no body of knowledge. . . . So what she produces is a simulacrum of scientific generalization. What we, experts in language, are asking for is forgery in language.
>
> (186)

The point is perfectly general: the student can offer only pseudo-thinking because she has no material to shape. Ponsot and Dean point out the symptoms of pseudo-thinking: misspelling ("the nervous stammer of writing"), shifting pronouns, vague reference, unidiomatic language, askew syntax, and jargon ("she has broken her native tongue and is trying to speak a foreign language").

(3) We can encourage the development of reasoning powers by encouraging what used to be called "critical thinking." We can make students argumentatively responsible. Lists and the standard approach of the neutral textbook must be rejected. Instead, materials should be argumentative—for example as a scholarly or scientific paper is, and students should be asked to identify the reasons and to assess them. They will, of course, be limited in their ability to do this as a strict function of what they know, but that is no reason not to do it. In oral contexts, similarly, students should be made to give reasons, to be held rationally accountable for their assertions.

On this score let me end with a final paradox. Science education tends to be the most dogmatic and full of appeal to authority. The result, familiar enough to people who have actually looked at science, is that most work in science is routinized, and that it has been the youthful, the perplexed, and the anarchic who have been the most creative.

Notes

[1] Thomas S. Kuhn's *The Structure of Scientific Revolutions* (1962) of course had enormous influence, although previous writers had raised serious difficulties with "the standard view." By now the literature is vast.

[2] The view is articulated in John Dewey, *Logic: The Theory of Inquiry* (New York: Holt, 1938), although Dewey is usually read as holding that there is such a thing as scientific method and that it is applicable to non-science.

[3] See, for example, Jerome Ravetz, *Scientific Knowledge and Its Social Problems* (New York: Oxford University Press, 1971) and Barry Barnes and David Edge, eds., *Science in Context* (Cambridge, Mass.: MIT Press, 1982).

[4] Kelley and Kreuger conclude, coincident with the argument of the forgoing, that we must consider the possibility that "abstraction is a preconceptual process involving nonpropositional modes of cognition such as perception" (64). The historically minded reader should here compare Aristotle on this problem. For Aristotle, "demonstration" was not sufficient to account for "science" (*episteme*). This required as well *epagoge*, misleadingly translated as "induction" or preferably as "intuitive induction." In the last chapter of his important and influential account of science in *Posterior Analytics*, Book II, ch. xix, he treated the power of the *nous* to "see" the "universal" in the "particular" and offered an analogy. This power arises, he said, "from sense perception, just as, when a retreat has occurred in battle, if one man halts so does another, and then another, until the original position is restored. The soul (*psyche*) is so constituted that it is capable of the same sort of process (100a 12-14).

List of Works Cited

Bruner, Jerome et al. *Readings in Cognitive Growth*. New York: John Wiley, 1966.

Kelley, David and Janet Kreuger. "The Psychology of Abstraction." *Journal of the Theory of Social Behavior*, 14 (1984), 43-68.

Ponsot, Marie and Rosemary Dean. *Beat Not the Poor Desk*. Montclair, NJ: Boynton and Cook, 1984.

Maintaining the Dialogue: General Education at Colgate University

Christopher Nevison

A liberal arts college provides the opportunity for continuing interactions between scientists, humanists, and social scientists that can be difficult to achieve in larger universities. Colgate University recently revised its traditional general education core program so as to strengthen these interactions between faculty in different disciplines.

The purpose of the general education program is stated in the Legislation of Colgate University, approved by the faculty in 1982:

> To engage students with some persistent, fundamental questions of Western cultures, as posed in classical texts and confronted today as current issues. . . . To demonstrate the kinds of understanding and forms of expression that can be employed in addressing such questions, in response to widely different human needs and capacities. The answers of modern science, of religious conviction, and of aesthetic sensibility are all necessary, legitimate forms of understanding, although each alone is partial and incomplete.

The newly revised curriculum is designed to emphasize these purposes in an interdisciplinary setting. The staff for all levels of Colgate's revised program are drawn from all parts of the university. The first in the four-course series, "The Roots of Modern Western Civilization," for example, has staff from mathematics, biology, physics, English, German, philosophy, religion, and political science. The second course in the sequence, "The Modern Experience in the West," has a similar diversity of faculty. These first two courses are taught in individual sections with a common syllabus. They provide a foundation not only for the remaining core courses but also for the whole Colgate curriculum.

For the third course in the program, students choose from among several dealing with non-Western cultures. These include courses on Kenya, India, the Black Diaspora, the Caribbean, and Women in China. Taught by humanities and social science faculty, each includes consideration of many common issues as well as topics important for each particular course. The diversity of the teaching staff, ranging from musicologists to political scientists, from religion specialists to anthropologists, ensures that each course treats its topic culture with breadth as well as depth. A lecture series each semester develops issues of common concern and establishes links with other courses in the program.

By the junior or senior year students complete most, if not all, of a distribution requirement in addition to the first three courses in the core series. They can then select one (or more) from several interdisciplinary courses that make up the final tier of the core program. Each of these courses studies an issue of contemporary concern from several perspectives. The courses are taught by teams of faculty, typically three or four in a given semester, drawn from different departments in different divisions of the college. The students are pushed to draw on the breadth of their experience from the earlier core courses as well as the expertise they have developed in their major or minor disciplines. Among the courses offered are these: "World Hunger and Food Supply," "Modern Man in Search of His Soul" (physics and philosophy), "Artificial Intelligence," "Innovation and Creativity," and "Episodes in the History of Science." Questions such as What values does science serve? How does science stimulate or stifle creativity? How can the humanities help the sciences to understand the creative process? are relevant to many of the courses. Two courses in particular address these concerns directly.

The course titled "Episodes in the History of Science" has been taught four times in the past few years. The staff includes at least one from the humanities—history or philosophy—with the others from different science departments. The first time the course was offered, the staff of four included an astronomer, a geologist, a mathematician, and a historian; the second time, a chemist substituted for the astronomer and a philosopher for the historian. Such combinations enable a rich selection of topics from the history of science. More important, however, we have been able to look at the development of science from different perspectives. Of course a philosopher or a historian adds a distinct perspective, but among the scientists different methodologies also lead to a rich interchange of ideas.

These courses are taught cooperatively by the team of instructors, with each present at all times and interacting with the others as appropriate. Unlike some other courses, it has not been a tag-team approach. All faculty have been involved at all times. This has been achieved in different ways, depending on class size. In two instances, large enrollments led us to teach large lectures with discussion sections. Although a series of lectures would be the responsibility of one of the staff, the others would attend the lectures and lead discussion of the material. In other instances, with three instructors and a smaller class size, the format has been a combination of lecture-discussion. Panel discussions involving the instructors are also included. In this way, the students are led to see the complexity of some of the issues raised in the course, issues such as, Where do hypotheses come from? What leads to a breakthrough in science? How do social and cultural factors affect the development of science? What enables one person to make a creative innovation where others have not? Do institutions stimulate or stifle creativity in science? The students are brought to realize that some critical questions about science cannot be answered simply by scientists. They have the opportunity to see a combination of individuals with diverse training grapple with these issues.

We have experimented with different ways of organizing this course. One method has been to take a theory about the development of science—for example, we have used Thomas Kuhn's *The Structure of Scientific Revolutions*—and use it to examine specific episodes in the history of science and in turn use those episodes to test the theory. A second way of unifying the course has been to organize it around a particular theme, such as creation and evolution. In this case, we examine critically the development of several scientific theories, such as cosmology, evolution, and genetics, with a view to understanding how and why they developed, and how they have affected knowledge and culture.

A specific example can illustrate how such courses work. I once taught a unit on the development of Euclidean and non-Euclidean geometries in cooperation with instructors from the sciences and a philosopher and a historian. The experience of working with this faculty enriched my understanding and teaching of this topic.

In this particular course, we concentrated on the parallel postulate. In the development of Greek geometry we see in its fruition, Euclid's *Elements*, an anomaly: the parallel postulate. Even Euclid seems to have recognized the difficulty since it is the most complexly stated of his postulates and since the application of it is delayed until it cannot be avoided, in the proof of proposition 29 in Book I.

Why the fuss? Why not accept the postulate along with all the others? At this point, we raised the issue of aesthetics in science: the attainment of elegance and simplicity as a primary value. Logically, there is no reason to consider the parallel postulate as different from the others. Aesthetically, it doesn't fit: it looks like a proposition, and it is not self-evident in the same way as the others. It is complex in statement and meaning. The appeal of finding a proof for the parallel postulate is similar to the appeal that Werner Heisenberg described in a conversation with Einstein on physics:

> You may object that by speaking of simplicity and beauty I am introducing aesthetic criteria of truth, and I frankly admit that I am strongly attracted by the simplicity and beauty of mathematical schemes with which nature presents us. (68-69)

The attraction of simplicity is such that for two thousand years after Euclid, mathematicians searched for proof of the parallel postulate. Although this was not a central question in mathematics, it was a recurring one that led to many important discoveries and ultimately in the nineteenth century to a whole new way of looking at geometry.

Why did it take until the 1820s for a breakthrough to occur? Kuhn's theory did not provide an answer. It did, however, demonstrate the strength of scientific paradigms and reasons why a Euclidean paradigm might persist. But the sources of change internal to science that Kuhn cites as the driving force behind paradigm shift do not apply: the anomaly was there from the beginning. All the ingredients for change were discovered by Saccheri and Lambert—indeed they would be credited with the discovery of non-Euclidean geometry if they had only recognized it. But they did not.

Yet from 1816 to 1826, no less than three mathematicians—Gauss, Bolyai, and Lobachevsky—independently recognized the same thing: the parallel postulate could not be proved and assuming its negation did not lead to contradiction. Why, after so long, did these men jump to this revolutionary conclusion virtually simultaneously? This question was given to the students, and although there could be no answer we speculated on the economic, political, and social changes as well as on the philosophical and intellectual developments. What I conveyed to the students was that this major creation was not simply a result of logical progression in mathematics, but it was a change in how one viewed mathematics and aesthetic judgments. And this change was not without consequences. To cite just one example, Einstein said, "To this interpretation of geometry I attach great importance, for should I not have been acquainted with it, I never would have been able to develop the theory of relativity" (Greenberg 238).

This example demonstrates specific ways in which questions about creativity in science can be raised. For a course focusing on creativity rather than the history of science, this could be a case for examining the ideas on creativity and science expressed by Bronowski in *Science and Human Values*.

What I would like to emphasize is the dynamic that an interdisciplinary approach brings to such a topic. Many questions were raised by the historian and philosopher, and discussion was enriched by the lively exchange that followed. Students deserve to see this exchange and become aware that the search for answers goes on.

One further interdisciplinary course is now being planned and deserves to be mentioned here. This will take as its topic the theme of creativity and innovation. It will bring together faculty from fine arts, anthropology, computer science and mathematics, and geology. It will consider questions involving creativity and innovation and their effects, the particular questions to be determined by the faculty involved. The theme of the course will be the cross-disciplinary study of what leads to creative insights in any field, how innovations affect that field and others, and how the creative process is the same or different for different fields

One approach to this course has already emerged. Two of the originators of the course are a geologist and an art historian. They have suggested that the instructors work from topics in their own fields to address the question of creativity. A particular example is the study of how plate tectonics was discovered and what its ramifications have been. Another topic they propose to discuss is Jackson Pollock's painting.

Another approach being considered is making direct comparisons of how creativity works in different fields and how one field directly affects another. A useful book for this approach is Douglas Hofstadter's *Godel, Escher, Bach: An Eternal Golden Braid* (1980). Here is a rich source for comparing the common elements of creativity in art, music, and mathematics (and a branch of mathematics with profound implications for computer science). The common sense of structure found in the work of Bach and Escher and the mathematics of Godel is developed beautifully in this book. One cannot leave the work without understanding the importance of an aesthetic sense in mathematics as well as in music and art. On the other hand, a well-defined consistent structure—the substance of mathematics—is the basis for the creative geniuses of Bach and Escher. Creativity comes from the struggle of the mind to shape our world, and in this case we see fundamental common elements in quite diverse fields, the theme of self-reference and variations.

Such comparisons are endlessly possible, of course, and in the context of teaching the challenge is to find an approach that opens the way for our students. As I have tried to indicate here, I believe that an interdisciplinary approach can be most effective, both for faculty and for students. It is important that the faculty involved work from a field or from examples about which they are very knowledgable; at the same time, however, the faculty must be willing to cross boundaries and address questions not usually asked in their field of expertise. The result can be a rich experience for all involved.

List of Works Cited

Greenberg, Marvin Jay. *Euclidean and Non-Euclidean Geometries.* 2nd. ed. San Francisco: Freeman, 1980.
Heisenberg, Werner. *Physics and Beyond.* Trans. A. J. Pomerans. New York: Harper and Row, 1971.

Panel Topic

Toward a Theory of Scientific Creativity

Creativity in Experimental Science

Tyrone Lai

It is now generally accepted that creativity plays an important role in theoretical science, for example, in the creation of theories and in the detection of problems. However, I wish to speak not about creativity in theoretical science but in experimental science. There are two reasons. One, it has been neglected. Two, attention to creativity in experimental science tells us much about both science and creativity.

There are understandable reasons why creativity in experimental science has been so largely neglected. The dominant view of science is hypothetico-deductive. In this view of science, the role of experiment is somewhat subordinate.

According to the current view, scientists attempt to solve problems in the theoretical structure of science. They do so by proposing theories that are then subjected to repeated testing. When theories pass tests, they are retained. When they fail, they are thrown out — provided there are replacements. In the current view of science, therefore, the interest is clearly on theoretical science. Theories are the important things. Only when there are theories to be tested are experimental scientists called in. The role of the experimental scientist in this view is somewhat like that of a judge: essential, requiring good ability, but not glamorous. The glamour belongs to the attorneys, the theoretical scientists presenting briefs for the various competing theories. In such a setting, it is no wonder that experimental science is neglected by philosophers, and with it creativity in experimental science. It is not that philosophers do not recognize the construction of a good experimental test for a theory requires ingenuity. They do recognize this; but beyond this, they have not much else to say.

I think that the hypothetico-deductive view of science provides only one half of the picture. Science is more complicated, more exciting than this. A more adequate understanding of creativity in experimental science would help us arrive at a fuller picture of science.

The hypothetico-deductive view of science is incomplete because it sees science as running only on one track. In fact, science runs on two two *parallel* tracks. On the one hand, there is progress in theoretical understanding: we advance from theory to theory (or, as some would say, from problem to problem). On the other, there is progress in the understanding of phenomena: more and more phenomena of different sorts come under study and are understood in terms of theories we have. This two-tracked development of science is not fortuitous. It is in fact essential to science's continued development. For this reason, we should not say, as some are tempted, let's concentrate on theory and apply it to phenomena *only* when the need arises. If we were to do this, I think science would suffer; its advance would slow dramatically, perhaps even stop. To see why this is the case, it is useful to remind ourselves that *experiments have to be designed*. We are more likely to have this reminder if we pay more attention to creativity in experimental science.

The design of experiments, of course, requires creativity. I do not think there is any dispute about this. However, an important point to remember is that creativity does not take place in a vacuum. In science as elsewhere, it usually requires preparation. Before becoming an experimental scientist, one must undergo training, learn the trade, become acquainted with various current techniques, and become familiar with various instruments. *Above all the prospective scientist must know in a practical way how this world operates.*

When we test a theory, we deduce from it an empirical prediction and then compare the prediction with observation. However, while many predictions can be deduced, not all can be used for testing. Some predictions are too difficult to check—for example, because there are too many interfering factors, or because they are not noticeably different from predictions derived from competing theories. This is where the ingenuity and knowledge of the experimental scientist enter. Of many possible predictions, the experimental scientist must pick the one or the few that can be unambiguously checked in an experimental situation brought about and controlled by that scientist. This cannot be done without a good stock of practical knowledge. Theoretical knowledge is not enough. One has to know how theories actually function in various kinds of actual settings.

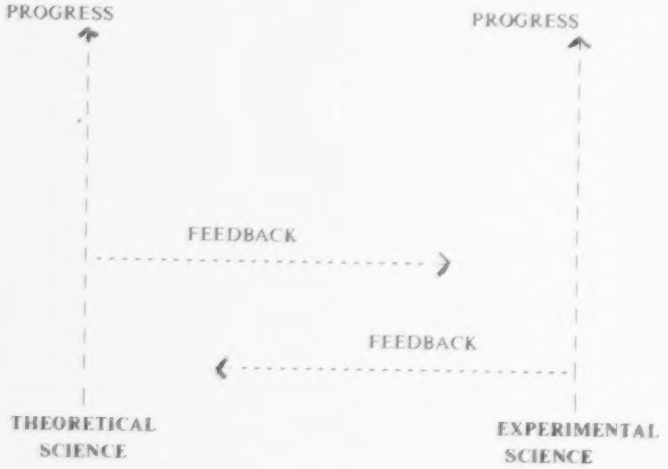
Now it is important to notice that this kind of practical knowledge that makes creativity possible for the experimental scientist has to be acquired largely in advance. There are two reasons. First, an experimental scientist cannot predict which theories will have to be tested eventually. If he were to amass a stock of practical knowledge only after identifying the theories to be tested, it would take too long before the test could be designed. (An architect may look for a few of the materials he needs to build a house after he has been commissioned, but his design will largely revolve around materials he already knows.) Second, and perhaps more important, it is often the possession of a particular piece of knowledge that *prompts* the experimental scientist to a particular experimental design. (A new construction method might prompt a particular design—as cathedrals were built around vaultings and arches.)

Therefore, in view of the need for design, the experimental scientist cannot spend his time just testing theories. He has to spend most of it applying theories to the understanding of this world, applying them to various phenomena. The stock of practical knowledge in science must be built up. Most experiments, by consequence, are designed not to test theories as much as the models that have been drawn up for the phenomena to be understood. The world is too untidy and complicated to apply theories to it directly. Idealizations and simplifications must be introduced through models, which are then tested.

The role of the experimental scientist is therefore not subordinate to that of the theoretical scientist. The experimental scientist is interested in theories; from time to time the experimental scientist tests them. But there are other interests to pursue, particularly those involved with understanding the world in a practical way.

Thus science develops along two parallel tracks. The theoretical scientist seeks to discover theories. The experimental scientists seeks to apply them. The two tracks are therefore not isolated but interact and influence one another (figure 1).

Figure 1: Mutual Feedback Between Theoretical Science and Experimental Science



The experimental scientist seeks to understand the world in the context of the theories provided by the theoretical scientist; the development of theoretical science is guided by the results of tests designed and conducted by the experimental scientist. Within this framework, both scientists engage in their creative work. The context is somewhat more complicated than the hypothetico-deductive view of science would give out. We can come to this fuller view of science by examining the way in which creativity manifests itself in experimental science.

Having discussed the context in which creative work in experimental science is carried out, I would like to point to three further aspects of this type of creativity.

1. Creativity in experimental science leads to both practical and pure knowledge. This I wish to emphasize. Experimental scientists seek to determine the worth of a theory or whether a model for a certain phenomenon is appropriate. These questions are addressed to nature, which does not speak any human language. This is the reason for experiments, which are a *means* of addressing questions to nature that nature can understand. Inasmuch as experimental scientists are concerned with a means of communication, their exercise of creativity in this instance is connected with practical knowledge. They are concerned with how to do things, especially in new ways, for each question is new, requiring a new experiment specially designed.

Communication is a practical art, but it can make use of technology. In communicating with nature, experimental scientists rely to a large extent on technology that they have had a hand in creating. Indeed, since the questions addressed to nature are seldom repeated, or when repeated have to be done so in different ways (as when we want to test the same theory by different methods), what is needed might be called a custom technology that does not serve a mass market (hence the layman never hears of it) but is tailor-made for the individual occasion.

While concerned to a large extent with the hows, the experimental scientist is not just a technician. Experimental science helps us to understand our world. The theoretical scientist helps us to understand the structure of our world, but the experimental scientist is interested in phenomena. Theories may yield hints, but the experimental scientist must design the models by which we understand.

Discovering an appropriate model advances our understanding. We should not consider the effort wasted if models yield no practical results; their value is intrinsic in permitting us to understand the world. The experimental scientist, therefore, occupies an interesting position—interested in pure knowledge like the theoretical scientist, and like the inventor interested in making things work.

2. Creative work in experimental science does not take place in isolation. I have already mentioned the two-tracked development of science. Now it is important to notice that this dual process, which requires mutual interaction, provides not only the context within which creative work in experimental science finds place but also discipline.

No one can tell experimental scientists how to draw on the materials available to them nor how to shape it. What keeps them on track? The answer to this question is the two-tracked process itself, for it requires both theoretical and experimental scientists to have done their work properly. If the results of experimental science are not accurate, the theoretical scientist is misled. And if this happens, the eventual result will be unfortunate for *both*. Because of their mutual dependence, these two groups of scientists must make every effort to uncover *objective* nature. (Also, they *have* to succeed to some extent.)

Mistakes do occur; sometimes there are even outright frauds. The theoretical/experimental system can withstand some of these mishaps. However, if the mistakes are major or if the deceptions serious, the scientific community pays with lost work-hours until one way or another the error is revealed. The two-tracked system cannot do without proper feedback for long. From such bitter experience, the community and the individual learn to discipline themselves.

Discipline and direction come to experimental science from a larger process of which it is a part; namely, the two-tracked process of experimental science/theoretical science. But the latter is itself part of a still larger process. Just as there is mutual feedback between the two sciences, there is feedback between science and technology. Scientific knowledge, whether of structure or of phenomena, is useful to the technologist. Experimental science, we have pointed out, is a form of technology in some respects and thus can benefit from technological advance. (Notice the role of computers in scientific research at the present time.) Science on the one hand, and technology on the other, thus again form themselves into another two-tracked process with mutual feedback. This still larger process cannot sustain itself if scientists and technologists are not professionally capable. Since this is the case it imposes further discipline on the experimental scientist, who is required to be creative but also to satisfy the primary objective of increasing our knowledge of this world. Participating in the larger processes makes it possible to satisfy both requirements.

3. People often think creative individuals possess tremendous power. After all, they are able to do what most others cannot. This is one view, but there is another. Creative accomplishments are but small steps in some larger process that transcends individuals and draws them into it. The Greek poets speak of the muses: the poets do not create—they are

the mouthpieces of the muses. Creativity in experimental science helps us to understand this view. Experimental scientists often work with questions that concern few others. The standards worked with are not set by them, but the scientists are dedicated to them. Even accomplished, the work may never have a major impact on the rest of the world. Yet it is this type of work that is essential to maintaining the larger process of science itself, technology, and through technology society at large. These larger processes require small creative steps, and many of them. The larger processes are not made up of these smaller steps through accumulation; they *evolve* as a result of these smaller steps. Sometimes these evolving processes accelerate; they flower and come into dazzling bloom. That is when the world notices. But the world sees a very different picture from that of the working scientist or the working poet. The world sees the blossoming as frozen in time, the work of a few individuals. It fails to see the dynamics behind the changing scene, that the individuals, essential and indispensible as they are, play but small parts in the whole drama. The dynamism comes from the fact that science, technology, and society are involved mutually in a highly dynamic process that has the tendency to draw individuals into them—much as musicians are sometimes driven into frenzy by the music they themselves make.

Scientific Unification Through Metaphor

Daniel Rothbart

Despite the well-documented widespread use of metaphor by scientists, especially in nineteenth-century British physical science (see Olson 1975; Hesse 1962), logical empiricists among others tend to claim that metaphor is nonessential and can always be replaced by clearer literal language. But this position denies to metaphor the essential role it has played historically in the formation of scientific theories by the unification of two fields. There is, in fact, evidence to suggest that scientific enquiry rests directly on the conceptual innovations arising from the use of metaphor in scientific settings.

I. A. Richards (1936) and Max Black (1962, 1979) have shown that every metaphoric statement includes a literal expression and a nonliteral. The interaction between these two allows features from the second subject to be projected onto the first in a way that "selects, emphasizes, suppresses, and organizes features of the primary subject" (Black 1979, 29). For example, in the statement "The theory of information processing is in its infancy," the primary subject is the theory of information processing and the secondary is its state of infancy. Such metaphors expand our understanding by extending the context in which we view the subjects. A further example is the famous clock metaphor used by seventeenth-century psychologists. "Each act of human behavior is the movement of a clock." Human behavior is usually seen as incompatible with clockwork movements, but by making these fields interact it is possible to suggest the property of being mechanically determined. This alters our conventional understanding of human behavior.

It has been argued that metaphors at best provide a feeling of familiarity but nothing more. In this view, metaphors, analogies, and models are merely pseudo-explanations (Hempel 1965, 240). This position is clearly correct about many metaphors. Talk of "wormholes" in general relativity or electron cloud in subatomic physics serves no more than pedagogical functions (Boyd 1979, 359). But in many other cases, metaphors express the inexpressible by capturing an aspect of nature that escapes the literal. More than pedagogical, such metaphors can become an important component of theories. For example, Maxwell's famous extension of electromagnetic field theory to an understanding of the propagation of light waves was grounded on metaphor. After he supplied a mechanical explanation of the origin of electromagnetic waves, he observed that a beam of electromagnetic energy would reflect off metallic objects, that such a beam would refract through glass, and that the beam's path could bend. These observations prompted him to describe light rays in terms of electromagnetic waves.

Maxwell's analogy illustrates the explanatory unification from metaphoric links between different systems. Simply put, unification occurs when the basic laws and concepts of one area are mapped out onto a second system as part of a new theory. Newton's particle mechanics, for example, drew from three Newtonian axioms: the initial application included the class of known planets, the Earth-Moon system, Jupiter and its satellites, and terrestrial classes of applications such as freely falling bodies and tides. This core of theory was then extended to comet-sun systems and the Jupiter-Saturn-Sun system (Sintonen 1984, 166–167).

But the binding force of unification requires that seemingly distinct and unrelated systems or views be in fact identical (Sintonen 1984, 158). In many cases the greatest challenge to unification lies in fulfilling this need. Scientists are frequently confronted with inconsistent definitions, the need for new concepts, or the elimination of familiar ones. In fact, a major aspect of "normal science" consists of reinterpreting the known in order to extend into the unknown.

A metaphor reorganizes how one thinks and visualizes by projecting new features and redistributing others. Maxwell's interpretation of light as a disturbance of the field created substantial indentities between light and electromagnetism. This allowed him to subsume optics into a system of general dynamics for matter in motion:

> The figure of speech or of thought by which we transfer the language and ideas of a familiar science to one with which we are less acquainted may be called Scientific Metaphor. There are certain electrical phenomena again which are connected together by relations of the same form as those which connect dynamical phenomena. To apply to (electrical phenomena) the phrases of dynamics with proper distinctions and provisional reservations is an example of a metaphor of a bolder kind.
>
> (1890, 227)

Another scientist who uses metaphors in this way (and a contemporary of Maxwell's) is James David Forbes, who studied the refraction of radiant heat. Links between radiant heat and light prompted Forbes to examine whether heat could be polarized like light. Forbes demonstrated that not only the polarization of heat but also all the fundamental complex relationships from the undulatory theory of light were true also of radiant heat (Olson 228). Newton's famous metaphor of sound to explain optical phenomena established new conceptual possibilities within optics, as illustrated by the relationship between the harmony of sounds and the "harmony of colors" (North 1980, 120).

During the seventeenth century, scientists believed that matter of each heavenly body tends only towards its own center of gravity. In particular, Gilbert argued that the tendency for an earthly body to unite to the earth is due to contact with the earth's atmosphere. Gilbert extended this principle as follows:

> All that is earthly unites itself with the earth's globe; in the same way all that is of the same substance as the sun tends towards the sun, all the moon's substance towards the moon, and the same for the other bodies which make up the universe.
>
> (Quoted in Hesse 1962, 128)

Gilbert concluded that all objects tend to unite to the atmosphere of the parent body.

A successful theory-expanding metaphor must by definition fulfill several requirements. First, it must be clear. Maxwell's metaphor was grounded on a relatively coherent conception of ether conjoined with the formal principles of electromagnetism. Second, it should ideally preserve all formal relationships inherent in both systems. Maxwell's metaphor did this since the core principles and equations are mathematically satisfied. Finally, the metaphor must account for the core concepts and must present a unified physical system.

These three requirements present necessary although not sufficient requirements for unification through metaphor. A theory-expanding metaphor represents one element of a paradigmatic picture of reality. In this respect, scientific knowledge is continually constructed and reconstructed by these fertile representations of the world.

List of Works Cited

Black, M. (1962) *Models and Metaphors.* Ithaca, N.Y.: Cornell University.

Boyd, R. (1979) "Metaphor and Theory Change: What Is 'Metaphor' a Metaphor For?" In *Metaphor and Thought.* A Oronty (ed.). Cambridge University, pp. 356–408.

———. (1979) "More About Metaphors." In Oronty, 19–43.

Forbes, J. (1838) "On the Undulatory Theory of Heat." *London and Edinburgh Philosophical Magazine and Journal of Science* 12: 545–559.

Hempel, C. (1965) "The Function of General Laws in History." In *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*. New York: Free Press.

Hesse, M. B. (1962) *Forces and Fields*. Westport, Conn.: Greenwood Press.

———. (1973) "Logic of Discovery in Maxwell's Electromagnetic Theory." In *Foundations of Scientific Method: The Nineteenth Century*. R. Giere and R. Westfall (eds.). Bloomington, Ind.: Indiana University.

Maxwell, J. (1890) *The Scientific Papers of James Clerk Maxwell*. W. D. Niven (ed.) Volume 1. New York: Dover.

North J. (1980). "Science and Analogy." In *On Scientific Discovery*, M. Grmek, R. Cohen, and G. Cimino (eds.). Boston Studies int Philosophy of Science, vol. 34. Boston: D. Reidel, pp.115–140.

Olson, R. (1975) *Scottish Philosophy and British Physics: 1750–1880*. Princeton, N.J.: Princeton University.

Richards, I. A. (1936) *The Philosophy of Rhetoric*. Oxford: Oxford University.

Sintonen, M. (1984) *The Pragmatics of Scientific Explanation*. Helsinki: Philosophical Society of Finland.

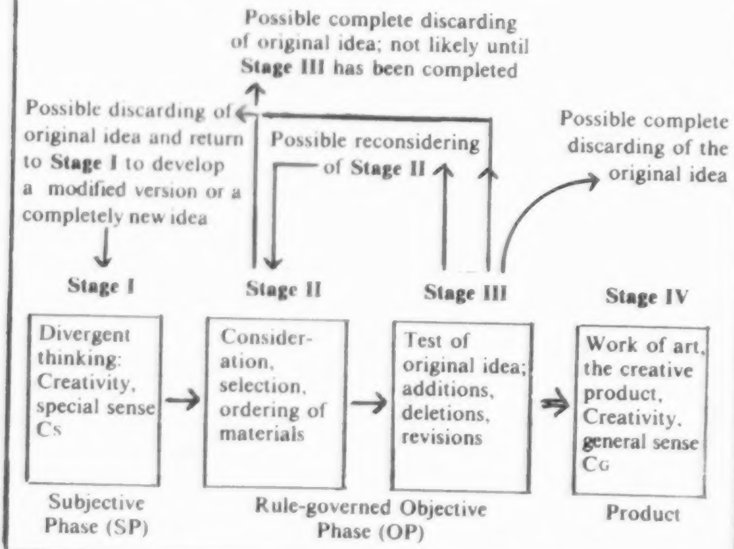
On Creativity and the Structure of Science

Paul C. L. Tang

Scientists often display a deep appreciation for the arts. Many also display a marked competence in them. What is the nature and source of this special affinity? One way of answering this question can be found by investigating the overall structure of art and music and comparing it with that of science. The result is a striking similarity.

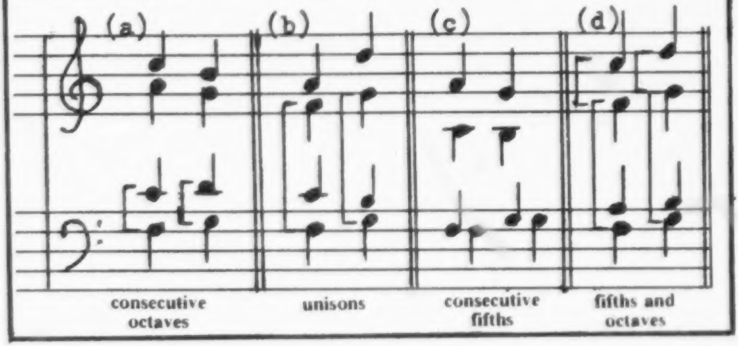
Stage I of the artistic process is highly subjective, non-mechanical, non-algorithmic, non-rule-governed, and marked by divergent thinking. The artist considers and selects his materials and tests his original idea, modifying it by additions, deletions, and revisions before arriving at the final artistic creation. The model depicted in figure 1 captures these phases.

Figure 1. The Artistic Activity


Possible complete discarding of original idea; not likely until Stage III has been completed
Possible discarding of original idea and return to Stage I to develop a modified version or a completely new idea
Possible reconsidering of Stage II
Possible complete discarding of the original idea
Stage I
Stage II
Stage III
Stage IV
Divergent thinking: Creativity, special sense Cs
Consideration, selection, ordering of materials
Test of original idea; additions, deletions, revisions
Work of art, the creative product, Creativity, general sense CG
Subjective Phase (SP)
Rule-governed Objective Phase (OP)
Product

Next comes the rule-governed, objective phase of artistic activity, a phase that is marked by convergent thinking. It is a phase that many people are less aware of when considering artistic activity. For example, in music there is the rule of traditional harmony that if two voices move in the same direction, they may not move by parallel fifths or octaves. Thus, the harmonic progressions displayed in figure 2 are incorrect:

Figure 2. Sample of Incorrect Harmonic Progressions



For an example of the rule-governed nature of painting, one has only to consult Leonardo da Vinci's writings, where the master discusses the rules to which any painter's imagination must be subject (see the *Notebooks*, vol. 1). Also, consider what the composer Igor Stravinsky (1970) says:

> *Inspiration, art, artist*—so many words hazy at least, that keep us from seeing clearly in a field where everything is balance and calculation through which the breath of the speculative spirit blows. It is afterwards, and only afterwards, that the emotive disturbance which is at the root of inspiration may arise.
>
> (50)

For Stravinsky, "All music is nothing more than a succession of impulses that converge toward a definite point of repose" (37-38), and composing is for him,

> putting into an order a certain number of these sounds according to certain interval-relationships. This activity leads to a search for the center upon which the series of sounds involved in my undertaking

> should converge. Thus, if a center is given, I shall have to find a combination that converges upon it. If, on the other hand, an as yet unoriented combination has been found, I shall have to determine the center toward which it should lead. The discovery of this center suggests to me the solution of my problem.
>
> (39-40)

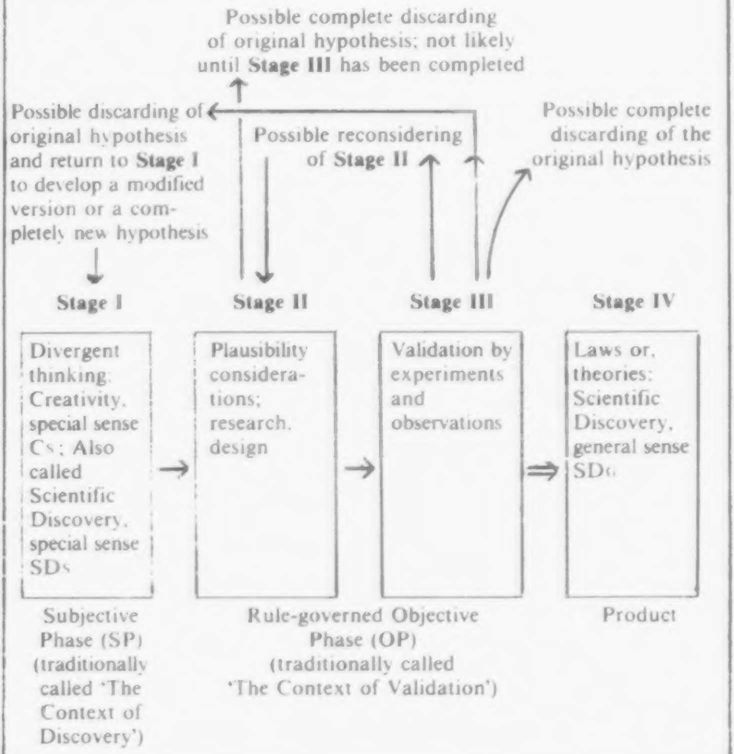
This reference to the notion of convergent thinking is especially interesting. In conversation with the conductor and author Robert Craft, Stravinsky responded to Craft's question of whether he (Stravinsky) regarded musical form as being in some degree mathematical:

> It is at any rate far closer to mathematics than to literature—not perhaps to mathematics itself but certainly to something like mathematical thinking and mathematical relationships. (How misleading are all literary descriptions of musical form!) I am not saying that composers think in equations or charts of numbers, nor are those things more able to symbolize music. But the way the composer thinks, the way I think, is, it seems to me, not very different from mathematical thinking. I was aware of the similarity of these two modes while I was still a student; and, incidentally, mathematics was the subject that most interested me in school.
>
> (*Conversations* 34)

In terms of the artistic product, we may say that the artistic creation is an interpretation of the world for which there may be alternatives, whether within one genre or across several. A sunset, for example, can be painted, described in prose, exalted in poetry, or captured in programmatic music.

The first stage of the scientific *process*, traditionally called "the context of discovery," consists in the formulation of hypotheses. Popper describes these hypotheses as bold, risky predictions that should be subject to rigorous testing or attempts at falsification. If they withstand such testing, they can then be provisionally accepted or corroborated as scientific *products* in the form of laws.[1] A number of corroborated laws pertaining to one specific area of investigation, such as the nature and behavior of gases, can then be systematized into a theory. One such is the kinetic molecular theory of gases, consisting of Gay-Lussac's law, Charles' law, Boyles' law, Dalton's law, and Graham's law. The various stages and possible maneuvers that can occur after the formulation of a working hypothesis are displayed in figure 3.

Figure 3. The Scientific Activity


Possible complete discarding of original hypothesis; not likely until **Stage III** has been completed
Possible discarding of original hypothesis and return to **Stage I** to develop a modified version or a completely new hypothesis
Possible reconsidering of **Stage II**
Possible complete discarding of the original hypothesis
Stage I
Stage II
Stage III
Stage IV
Divergent thinking: Creativity, special sense Cs; Also called Scientific Discovery, special sense SDs
Plausibility considerations; research, design
Validation by experiments and observations
Laws or, theories: Scientific Discovery, general sense SDG
Subjective Phase (SP) (traditionally called 'The Context of Discovery')
Rule-governed Objective Phase (OP) (traditionally called 'The Context of Validation')
Product

I wish now to focus on Stage I. What is the nature of the process by which fruitful hypotheses are generated? Is there a logic or an alogorithm of scientific discovery? Francis Bacon, J. S. Mill, and, more recently, Norwood Russell Hanson all have claimed that there is.[2] Most contemporary philosophers of science would disagree. For example, Carl Hempel compares mechanical rules of discovery to those of multiplication and argues that if there were such an effective means of scientific discovery, many chronically perplexing problems—for example a cure for cancer—would have been solved on the basis of probability (14). He doubts whether such a logic could ever be formulated, in part because scientists employ theoretical terms that do not occur in the descriptions of empirical findings on which theories rest. However, Hempel concedes that a scientist may infer a hypothesis as long as it contains no "novel" terms.

Hempel discusses theories about atomic and subatomic structure, where novel terms such as *atom*, *proton*, *neutron*, and *psi-function* are not descriptive of such empirical observations as the spectra of various gases, tracks in cloud and bubble chambers, and so forth. In this case, a scientist cannot infer a hypothesis. However, in determining the relationship between the length of a copper wire and temperature, one might argue that a scientist *could*. After plotting the data and drawing curves, the scientist finds that the length varies directly with the temperature; hence, a law is assumed (length varies directly with temperature) by a logic of discovery (inductive inference). The hypothesis contains no new terms and is expressible by such concepts as temperature and length, which are also used in describing the data. Hempel notes that this procedure is still not really a "logic" since it presupposes an antecedent, less specific hypothesis (i.e., that a single variable—length—is a function of another single variable—temperature). We could then ask where *this* hypothesis came from: and whatever the answer, it seems clear that this latter did not arise from empirical observation.

What then is the nature of hypothesis formulation? I believe that this stage is *creative* because it is highly subjective and non-rule-governed, involving what psychologists call "divergent thinking." Moreover, it is very similar to Stage I of the artistic model. One has only to think of Kepler's study of planetary motion—a study marked by the scientist's passion (almost obsession) to demonstrate a mystical doctrine about numbers and about the music of the spheres—or of Friedrich Kekulé and his famous dream of snakes that led him to arrive at the structural formula of the benzene molecule.

Scientists themselves tend to talk of their discoveries as illogical and intuitive. The biologist Albert Szent-Gyorgi described his work in the following terms:

> Naturally like all scientists, when I publish or speak about my work, I like to make it appear as though it has been one straight line, one preconceived logical unit . . . but while I work I usually do not know where I am going. I just follow hunches. I dream up all sorts of theories at night and then disprove them in the laboratory the next day. Checking a hunch, sometimes I see some discrepancy, something unexpected—then I follow it up. Success depends upon whether the hunch was good or bad. (34)

Einstein echoes these observations:

> There is no logical way to the discovery of these elemental laws. There is only the way of intuition, which is helped by a feeling of order lying behind the appearances. (Beveridge 72)

Furthermore, the products of science—its laws and theories—share with artistic activity in being interpretations of the world. As the contemporary American philosopher W. V. Quine has argued, these theories are underdetermined by the observation base (313-320).

The empirically grounded process-product models of art and science are also models for each other in the sense that they cause us to notice many underlying similarities. In the model for art, the objective phase resembles that of the scientific model. This objective phase needs to be emphasized. In the model for science, the subjective phase resembles that of art, but in this case the similarity is less controversial and is more familiar.

We should note that the scientist's creativity is very much intertwined with the problem at hand. In short, creativity for the scientist is a form of problem-solving. However, I believe that the same is true for art. Leonardo da Vinci's preliminary drawings for *The Last Supper* demonstrate his working to solve problems caused by his intention. Leonardo has chosen to depict an earlier moment in the story—when Christ first announces that one of his disciples will betray him—rather than the more traditional later moment when Judas is identified (Hartt 457-459). In his preliminary sketches, Leonardo experimented with the traditional pattern; there are sketches of each apostle, with particular attention paid to capturing each man's psychological state. The received opinion among art historians is that Leonardo could not solve the problem of how to portray the complex psychology unless he chose the earlier moment.[3]

Creativity seen as problem-solving does not contradict my earlier claim that creativity, whether artistic or scientific, is non-algorithmic. Scientific creativity requires intuition, imagination, and insight. Furthermore, for those cognitive scientists and researchers in artificial intelligence who might claim to be able to program creativity (indirectly, perhaps, by programming scientific discovery), I can say only that their claims most likely involve conceptual confusion. To say that some product is creative is just to say that it was not produced by any algorithm or any set of mechanical rules. To claim that a computer can be programmed to be creative is a logical contradiction.

Finally, I should like to propose some general factors that may enhance scientific creativity. First, I believe that a broad background in several scientific fields—if not also in several fields in the arts and humanities—may increase the creative powers of scientists, especially in allowing them to make novel connections. To aid in developing divergent thinking, scientists should make frequent use of analogical reasoning, models, and metaphors. Finally, they should be critical, be prepared to question traditional propositions, be willing to blur distinctions if necessary, and be able to cross the disciplinary boundaries as needed. Of course, these proposals reduce to empirical claims, and I, for one, would be interested in testing, refining, and adding to this set of factors.

Notes

[1] See Popper's *Conjectures and Refutations* (New York: Harper and Row, 1968). See also his *Logic of Scientific Discovery* (New York: Basic Books, 1959). The title of this second book is something of a misnomer, for Popper does not believe there is a logic of discovery.

[2] Herbert Simon is currently researching computer simulation of scientific discovery. But whether he addresses the issue of creativity is not clear. See the article by Gary F. Bradshaw, Patrick W. Langley, and Herbert A. Simon, "Studying Scientific Discovery by Computer Simulation," *Science* 222 (1983): 971–975.

[3] See Paul C. L. Tang and Arne R. Leonard, "Creativity in Art and Science," *Journal of Aesthetic Education*, 19 (1985): 5–19. We discuss this particular example in a slightly different context.

List of Works Cited

Beveridge, W. I. B. *The Art of Scientific Investigation.* New York: Vintage Books, 1957.

da Vinci, Leonardo. *The Notebooks of Leonardo da Vinci.* Ed. Jean Paul Richter. London, 1883; New York: Dover, 1970.

Hartt, Frederick. *History of Italian Renaissance Art.* New York: Harry N. Abrams, 1979.

Hempel, Carl G. *Philosophy of Natural Science.* Englewood Cliffs, N.J.: Prentice-Hall, 1966.

Quine, W. V. "On Empirically Equivalent Systems of the World," *Erkenntnis* 9 (1975): 313–328.

Stravinsky, Igor. *The Poetics of Music in the Form of Six Lessons.* Cambridge, Mass.: Harvard University Press, 1970.

——— and Robert Craft. *Stravinsky in Conversation with Robert Craft.* Berkeley: University of California Press, 1980.

Szent-Gyorgi, Albert. *The Way of the Scientist.* New York: Simon and Schuster, 1966.

Panel Topic

Science and the Arts

Art and Science: Creation or Discovery?

Sharon Bailin

The arts generally supply the prime example of the creative achievements of humanity and unequivocal examples of imaginative constructs. The realm of science is somewhat more problematic, however. While we certainly do attribute creativity to some of the most notable scientists, for example Newton or Einstein, there is no created product in the same way as there is in the arts. It has been argued that while art involves the creation of new and imaginative artifacts, science involves the discovery of the way the world really is; while art involves creation, science involves discovery.

The extent to which art and science differ with respect to their creativity has important implications for education. If, for example, the scientist is the totally objective observer of nature and discoverer of facts, then scientific training should emphasize technical knowledge, deductive reasoning, and scientific method. If science is a more creative endeavor, even resembling art, then the scientist should become more like the artist—an imaginative creator, a divergent thinker, a rule breaker, who "lacks prejudice to a degree where he can look at the most 'self-evident' facts or concepts without necessarily accepting them, and, conversely, allow his imagination to play with the most unlikely possibilities" (Selye, cited in Kuhn 226). Here I will argue that the first picture of science is inaccurate, and the second does justice neither to science nor art.

How creative is science? Baconian science would seem to allow very little room for creativity. According to this view, the scientist works according to a strict method that involves unbiased observation, deductive reasoning, and testing leading to a provable theory and thus to facts about the world. Bacon himself considered imaginative speculation as fancy and idle "brain creations."

This idea that scientific theory can be proven by the evidence gathered through observation and experimentation has been severely attacked in recent years. Hume, for example, has shown that a universal cannot be derived from any number of particulars, and hence no number of facts can logically entail a theory (I.III.vi). Moreover, even the notion of fact has been shown to be problematic. What we observe in a test or experiment is deemed a fact, and yet the very act of observing is theory-laden, involving perception dependent on previous knowledge and experience, and containing theoretical assumptions. The distinction between fact and theory is by no means clear-cut.

The falsificationist view acknowledges the problem of induction but attempts to rescue the empirical basis of science by maintaining that, although no number of specific instances is sufficient to prove a theory, a counter-instance is sufficient to disprove or falsify one. But the difficulties of such a falsificationist account have been demonstrated by both Kuhn and Feyerabend, who show that falsification is not, in fact, a characteristic of actual scientific practice. There are always anomalies in theories, and scientists do not abandon theories that would be refuted according to the falsificationist view. They tend to remain committed to a theory and to question the evidence and the experimental conditions, or to shore up the theory by means of auxiliary hypotheses rather than abandoning it.

Kuhn believes that scientific activity is characterized by a succession of paradigms and thus by radical shifts in the perspective from which we view scientific phenomena, categorize data, and organize research. He maintains, further, that psychological factors and consensus among scientists are largely responsible for determining which paradigm succeeds. Feyerabend points out that alleged scientific method is constantly violated in actual practice, that there are metaphysical presuppositions underlying every theory, and that irrationality is, and must be, a part of scientific activity. He claims that the only method that holds universally is "anything goes." Science does not provide us with an objective method for discovering certain knowledge about the world. Science is thus another of mankind's imaginative artifacts, not unlike religion or mythology—or art.

Some philosophers attempt to maintain a demarcation between science and non-science and to salvage the rationality of science. Imre Lakatos, for example, claims that science must be viewed and evaluated not in terms of individual theories but in terms of competing research programmes. A rational choice can be made between rival research programmes according to which one has excess content (predicts some novel unexpected fact) some of which is corroborated. Lakatos admits that some of the factors that Feyerabend and Kuhn emphasize, such as commitment to theory or metaphysical basis, operate in scientific activity. He also admits that science is fallible, but he denies that any of this constitutes irrationality. He views it, rather, as part of the internal mechanism of scientific progress and thus as perfectly rational. Lakatos attempts to defend science as a special way of knowing, distinct from other sorts of activities and characterized by a specific methodology that can be upheld as rational.

According to such a view, science seems not to involve a set, simple method characterized by unbiased observation, experimentation, and deduction. Moreover, there is no clear and knowable accord between scientific theories and reality, so science is not mere discovery of what is out there in the world in any straightforward way. Rather, this more complex relationship involves the construction of theories that include presuppositions and interpretation, but also bear a certain type of strong connection with empirical data. Science is an extremely highly constrained activity, yet in the context of these constraints new and highly significant products are produced. Herein lies the creativity in science.

How does this compare with creativity in art? I think that the arts strike us as an obvious example of creativity because they involve products that are created through the imaginative activity of the artist. Artistic artifacts are seen as freely created products of unconstrained imagination, unlike the products of science, which must fit the facts and reveal the world. It might be instructive, then, to look at the extent and nature of the constraints that operate in artistic production.

One constraint that does not seem to be present in the arts is the requirement of conformity with empirical data. Works of art are not tested, nor can they be verified as accurate. There is a sense in which works of art can represent reality with varying degrees of accuracy. Thus one landscape might be truer to life than another. But art cannot really copy reality—it can only transpose it. It is a creation of the artist's imagination. A work sometimes allows us to see a new aspect of a subject, and we might feel that the work is somehow true. This does not mean that this particular rendition is necessarily truer than another, however, but rather that we recognize and can relate to this aspect of the subject. The truth of a work, if it makes sense to refer to truth at all in this context, is emotional, based on what is evoked and not really pictorial. There is not some overriding criterion of truth according to which works can be measured. As Gombrich states, "The truth of a landscape is relative" (49).

Although there is no criterion of artistic truth and no necessary requirement of imitative accuracy in portraying the world, nonetheless artistic production is by no means totally free and unconstrained. There are numerous influences on what is valued in art, and these relate to the role that art plays for us. Art must have some sort of connection to people and their experience. It must provide for aesthetic experience and aesthetic appreciation. Such aesthetic appreciation does not reduce to mere subjective reaction, however, and the factors that affect this appreciation are the same ones that affect how art changes and develops.

The primary manner in which art changes is through the formulation and solution of specifically artistic problems. Thus one factor in our valuing of works of art relates to their place in the discipline—to how well they have solved existing problems and to whether they have developed new problems and a new direction in which art can develop. This is the principal basis for artistic value. Artistic development and value are influenced also by the state of technology both directly related to art and to society in general. Developments in other arts may also affect a particular art form. Finally, economic, political, and social conditions have some role to play in shaping an era's sensibility, determining both what is produced and appreciated.

In science, the primary criterion for value is similar to the first factor mentioned above. Like art, science develops through the formulation and solution of inherent problems. In this respect, neither artistic nor scientific activity allows the free rein of imagination, both being highly constrained by the traditions that define them. For the arts, this relates to the possibility for aesthetic appreciation. In the sciences, there is no parallel dependence on people's sensibilities. In fact, some of the other kinds of factors that affect the way we value art, the psychological and sociological influences, are explicity ruled out in science, and theorists who want to uphold a criterion of demarcation between science and non-science claim that one can and must separate the question of the psychology of theory choice and change from the question of evaluation. In art, however, the factors that affect change are closely related to the reasons why we value art as we do. It does not seem reasonable to ask in the case of art whether we ought to value what we do, but this seems to be the crucial question for science.

Yet it might be argued that a form of aesthetic criteria affects theory choice in science. Scientists frequently claim that considerations such as simplicity, elegance, unity, or beauty play a role. There are a number of possible explanations for this. One is that the world is itself constituted according to aesthetic criteria, and that they are a guide to truth. It does not seem, however, that we have any grounds for believing that the world is simple rather than complex or that it conforms to our aesthetic sensibilities. Another explanation might be that the reliance on aesthetic criteria is related to human capacities and preferences as practitioners of science. (It is easier for us to deal with a simple theory.) Another interpretation, and one that I find particularly cogent, is that aesthetic considerations are reducible to other sorts of criteria such as growth (Lakatos 173–174). Indeed, I think it is easy to see the strong connection between an ostensibly aesthetic criterion such as symmetry and a non-aesthetic one such as predictability (Smith 94-97). If this view is correct, the aesthetic considerations are irrelevant and the notion of sensibility is extraneous.

Another basis for comparing scientific and artistic constraints is provided by the notion of progress. In light of the difficulties encountered by the view that scientific theories are evaluated through some simple connection to the facts, it has been suggested that scientific value might be connected to some notion of progress. Lakatos, for example, proposes that a theory needs to fit the facts, but not in the narrow sense that evidence can falsify it. Instead it must promote the growth of the research programme as a whole. Fruitfulness may then become a requirement for scientific theories.

Does art need to be fruitful? We do value innovative artworks that open up new approaches. We don't usually value gratuitous novelty but do admire works that announce new artistic development—Picasso's cubist paintings, for example. But a work's failure to lead to new development does not diminish it. In science, the opposite is the case: if a theory does not lead to further discovery, it is discarded. Moreover, in art, a work may stand as exemplar of an existing school, marking a culmination of a style; there is no parallel for this in science.

Is it possible to talk of progress in art as well as science? Art does seem to develop, but art works do not necessarily improve over time. In science a new theory must be an improvement if it is to be valued. A new school of art does not need to encompass the work of its predecessors; for example, Impressionist landscapes did not have to do more than those preceding them. There is no linear progression in art; new styles add new ways of seeing, but there is no standard goal to which all works aspire. Such a standard is continually sought in science, however.

This comparison between science and art has shown that there are a number of misconceptions about both. First, the traditional picture of science as discovery is flawed: the connection between scientific theories and the world is by no means straightforward. Second, the picture of art as freely flowing unconstrained imagination is equally incorrect. This means that we must train our scientists to be more than impartial observers and employers of set methods—they must be imaginative. This does not imply unfettered fancy, however, since science progresses through the solving of problems that grow out of the existing scientific tradition. Scientists must understand the problems of the discipline as it exists and have a grasp of the scientific enterprise. As Kuhn puts it, "the productive scientist must be a traditionalist who enjoys playing intricate games by pre-established rules in order to be a successful innovator who discovers new rules and new pieces with which to play them" (237).

Similarly in the arts, the artist needs the basic understanding of the tradition and the discipline of acquired, essentially artistic skills.

Neither art nor science is characterized, then, by undisciplined imagination; both are bound by the limits and traditions of the disciplines. Yet such disciplines evolve through the creation of new products that sometimes transcend these very limits in order to further the development of the tradition. Creativity is characterized by significant achievement, and, when looking for creative achievement, one must look to science as well as art.

I would like to acknowledge the assistance of a fellowship from the Social Sciences and Humanities Research Council of Canada.

List of Works Cited

Gombrich, E. H. *Art and Illusion.* New York: Bollingen Foundation, 1961.

Hume, David. *Treatise of Human Nature* (1739). Ed. D. G. C. Macnabb. London: Collins, 1962.

Kuhn, Thomas. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press, 1962.

Lakatos, Imre. *The Methodology of Scientific Research Programmes: Philosophical Papers.* Vol. 1. Cambridge: Cambridge University Press, 1978.

Smith, Chris Llewellyn. "Symmetry and the Laws of Nature." *New Scientist* (October 1981): 94–97.

Aerial Perception

Margret Dreikausen

For several years I have been painting landscape as seen from the air. This has led me to investigate the subject of "aerial perception"—the earth as seen from above—but not only from an artistic and aesthetic point of view. I have researched connected sciences, including geography, geology, meteorology, oceanography, hydrology, air photography, and space technology, all of which in turn have influenced my work. In my book, *Aerial Perception: The Earth as Seen from Aircraft and Spacecraft and Its Influence on Contemporary Art* (Philadelphia Art Alliance, 1985), I discuss contemporary artists whose work has been influenced and inspired by this relatively new perspective. I have found that modern science and technology enable us to experience a synoptic view of the earth and its surrounding atmosphere.

Historically, art has reflected the social and cultural philosophy that created it. As art is a product of a particular era, artists are influenced by politics as well as by science, and these alter perceptions of the world. Medieval art, for example, was founded on Christianity. Its pictorial symbolism echoed religious and philosophical thought. Life on earth was only temporally significant; hope for an afterlife focused earthly vision on the heavens. On the other hand, the Renaissance interest in scientific learning and renewed interest in daily life on earth was reflected in the art of painting and sculpture. Artists such as Filippo Brunelleschi, Leonardo da Vinci, and Michelangelo Buonarroti strove for realism, a basic tenet of classical Greek art.

Leonardo Da Vinci is known to us not only as an artist, but also as a scientist and an inventor. His interest in visual appearance led him to examine the physical aspects that created it. He was particularly interested in the atmosphere, and it was he who explained aerial perspective to the artist.

Aerial perception—the earth as seen from aircraft—is relatively new as such. However, the bird's eye view of landscape as seen from mountain tops or high buildings has been familiar for many centuries. Leonardo was among the first to study landscape in this way: he studied landscape from high places and transferred these studies with an oblique viewpoint onto topographic maps with a vertical view. In effect, he drafted geographic maps, a fine example of which is the preparatory sketch and subsequent map showing the Chiana Valley (ca. 1502) now housed in the Royal Library at Windsor Castle.

His first sketch depicts the real landscape; the map displays the vertical viewpoint, for which Leonardo probably walked the valley, taking measurements to calculate the map's dimensions. He might have visualized how the topography might appear from a vantage point "suspended" in the air when designing his secret flying machines. But his drawings of landscape seen from high points deal not only with the earth seen from above, they also approach problems of perspective and atmosphere. Leonardo's well-known sketch *The Alpine Village* illustrates his particular concern for the physical composition of atmosphere at high altitudes. He devotes much time to aerial perspective, keeping it very distinct from linear perspective.

The term that I have been using, *aerial perspective*, was originally coined by Leonardo da Vinci. He applied it in particular to his recognition of how color changes toward the distant horizon due to the intervening atmosphere. He was the first to apply the theory of color gradient to art work, creating the illusion that painted objects recede into space toward the horizon. To suggest this depth, he gave a bluish tint toward the distance. He noted also how sunlight is scattered by the atmosphere, changing with atmospheric conditions, time of day, and the extent of the distance involved. He came to realize also that light and color change with increasing altitude.

Through the simultaneous invention of flight and photography, a new vision of our world became possible. Eighteenth-century balloonists had been fascinated by the new panorama, and artists very shortly began to produce lithographs to satisfy public demand. In 1859, the Parisian photographer Gaspard Felix Tournachon succeeded in producing the first aerial photograph. From the mid to late 1800s, when photography and flight were still incipient, these lithographs and photographs were extremely popular in Europe and America. At the beginning of this century, the Italian futurists were fascinated by these perspectives; Marinetti in particular declared the aerial view as the modern perspective for painting.

With the development of photography in the nineteenth century, artists became interested in the study of motion. Edward Muybridge used the new technology to study the continuous movement of bodies, mostly human and equine. Perhaps his most famous photographs are those taken in 1887, which show a man performing a standing broad jump; also well known are his various studies of animal locomotion. These photographic studies were to be an important factor in Edward Degas' paintings, especially those of jockeys on horseback.

Early twentieth-century futurists were influenced in turn by rayographs—medical studies of bone structures taken by Marey (Jules Etienne). These medical photographs rendered bone structure transparent. It was found that as various photographs, especially of limbs, were superimposed and assembled, they gave the impression of continuous movements. Giacomo Balla's painting, *Dynamism of a Dog on a Leash* (1912) and Marcel Duchamp's *Nude Descending a Staircase* of the same year are examples of Marey's strong influence.

Because of camera and infrared photography we are in an even better position to recognize how our perception of landscape is altered by altitude. We can judge this for ourselves from airplanes and ballons, but most of us experience the view from outer space through satellite photography. Multispectral lenses, using filters and film sensitized to wavelengths outside of the human spectrum, reveal yet more and permit us to see through the eye of the camera. When infrared photographs are juxtaposed with photos taken with regular film, it is possible to recognize the greater detail available in infrared photography.

Artists have always seen the world through the looking-glass of their time—the changing *weltanschauung*. The modern painter thus sees the world now through the different "eyes" made possible by science and technology. Whole new wave lengths become visible, far exceeding the forty percent normally available to the human eye. A comparison of a graph of human vision with the photographic spectrum suffices to show how limited is the human.

Advanced space technology now allows us to follow the movements of clouds and to observe the cosmos. The synoptic view of earth is enlarged with higher altitudes but also with greater speed, as speed brings perceived and remembered images closer in time. As satellites orbit the earth, time condenses and all-encompassing perspectives of the globe and cloud cover are transmitted back to earth.

Leonardo also anticipated the visual perception of storms. At the Windsor Royal Library are Leonardo's series, *Deluge*. These drawings depict swirling patterns of storm clouds that strongly resemble space photographs of cloud eddies and storm and hurricane formations. The charcoal drawings represent cosmic violence, echoing Leonardo's descriptions of cataclysmic storms in his scientific studies. NASA photography now shows the movement of warm and cold air as the basis for the swirling cloud formations Leonardo explored. In his sketches, Leonardo examined these essential forces, the structure of whole cloud-formations.

Space exploration has variously stimulated contemporary artists, as I have shown in my book. Nancy Graves and Charles Ross are two examples. They base some of their work on scientific studies of outer space. Other artists pursue the possible symbolic meaning of space exploration, and space artists sometimes envision hypothetical, intelligent life forms on hypothetical planets. In a catalog accompanying an exhibit of Nancy Graves' 1972 moon region paintings, critic Martin Cassidy had the following to say:

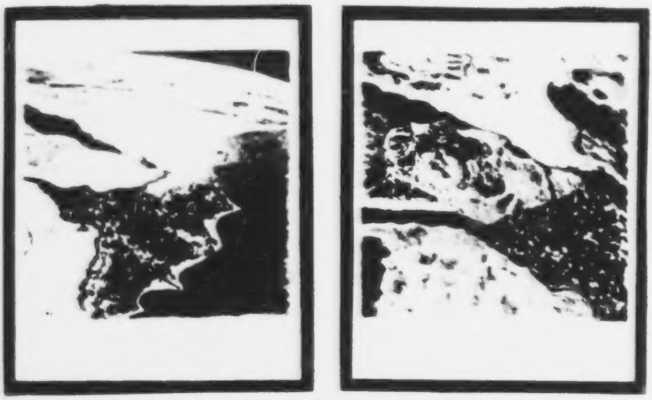
> Science traditionally has been the exemplary prober of the universe. Today there is a growing intimacy between these often polar activities, science and art. Together they constitute man's pre-eminent function. The artist's imagination must serve as a liaison between what we know and what we are.

Nancy Graves incorporates such disparate scientific disciplines as anthropology, oceanography, and astronomy (particularly of the Moon and Mars) in order to suggest the future in her work. A 1974 exhibit at the Emmerich Gallery displayed works based on NASA photographs and nimbus weather satellite photos. However, Nancy Graves' paintings are not concerned with clarifying air currents or cloud cover movements. Leonardo da Vinci studied natural forces in order to depict, scientifically as well as artistically, the development of storms, as in his deluge series. Today scientists explore the universe, and Nancy Graves uses their discoveries as the basis for artistic depiction. She seems to choose confusion deliberately to achieve a pictorial effect.

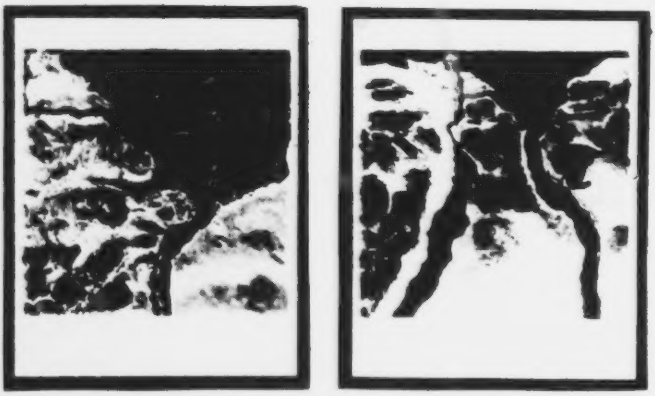
Charles Ross, on the other hand, originally wanted to be a scientist or mathematician, and he is strongly influenced by science in his art. His recent work deals with light as a source of energy affecting life, earth, and the universe, and light as a source of all visual perception. Light as energy and measure of time is the major conceptual idea in his "solar burns" as well as his "star maps," which were shown in 1977 in a joint exhibit at John Webber Gallery and Susan Caldwell Gallery in New York. The "solar burns" are the visual records of the sun's energy over a one-year period, marked on wooden panels. These experimental pieces show "the annual shape of time as drawn by the sun; compressed light recorded its own narrative along a double spiral" ("Ross," file at John Weber Gallery by David Shapiro and Lindsey Stamm, 4). The star maps of the Milky Way are based on photographs of the stars in the astronomical atlas of the heavens, the Falkau Atlas by Hans Vehrenberg. Susan Tower comments in the LaJolla catalog accompanying an exhibition of Ross's work:

> It has been speculated that in the history of Western thought two of three main entities formed by God, Man, and Nature are subsumed by the one which is historically privileged by each cultural era. In our present time, Nature is the enclosure in terms of which the identity of Man and God are questioned and redefined.

Figure 1: *The Delta.* Four sequential drawings by the author, 1985. India ink on paper, 24" x 19".



The Delta I *The Delta II*



The Delta III *The Delta IV*

In 1975, The Goethe House in New York exhibited paintings by a German artist, Tilman Kayser. His fantastic imagery conveys awe and wonder much like that prevailing in John Glenn's poetic descriptions of space, which appeared in *National Geographic* in 1962:

> The setting sun wraps a scarf around the earth's curving face. The speed at which the sun goes down is remarkable. The white line of the horizon sandwiched between the black sky and dark earth is extremely bright as the sun sets . . . the horizon on each side of the sun is extremely bright, a bright arc extending as far as we can see. It is made more intense by the darkness of the space above it and the dimness of the earth below . . . At the capsule's speed the sun sets 18 times faster than on earth. This is the orbital twilight—one of the unique sights of space travel.

In Kayser's work, 'landscape' is implied symbolically by straight and curved horizons, spheres, deep space, and textures that lead to associations with earth, oceans, skies, and our planet in space.

Other contemporary artists exhibit a similar kind of awe and wonder in their paintings. They envision landscapes for planets and stars not yet explored and create unknown planets with strange life-forms. This tendency is manifest also in movies such as *Star Wars*. Imaginary landscape anticipates scientific discovery. *The Planetary Report*, published bimonthly by the Planetary Society of which Carl Sagan is president, frequently reproduces work by these artists. Among them are William K. Hartman, David Hardy, Mark Paternostro, Michael Carroll, Alan Gutierrez, Pamela Lee, and Ron Miller. Their paintings are executed realistically—with believable space and imagery in Renaissance tradition.

Today, science is our greatest endeavor. The artist's imagination helps us to envision the possibilities of life-supporting planets. It is fitting to close with a passage of acknowledgment from the sciences. The Air and Space Museum in Washington D.C. introduces its art collection with the following words:

> Artists, it has often been said, are the weather vanes and prophets of history in the making. They record what they see, add what they know, remember and feel, and thus immeasurably expand our knowledge.

Order, Process, and God:
An Exercise in Creative, Yet Reasoned, Mythology

James E. Huchingson

Recently, while rereading William James' lectures, *A Pluralistic Universe*, I was intrigued anew with his perceptive discussion of the rationalist and the empiricist approaches to the order of nature and with the implication of these for the notion of God.

The amazing progress of science in this century has muted, but not mooted, the tension between rational and empirical philosophies. Because they understand that success is sufficient justification for their efforts, most scientists do not normally address these larger questions. Additional philosophical warrant is simply not required. Scientists seldom pursue, for example, the question of why the two approaches, so different from one another, seem to produce knowledge when teamed together. What kind of universe reveals itself to *both* forms of inquiry?

Today, frontier science is involved in a thorough examination of its first principles. Scientists, as well as students of science from many humanistic disciplines, are raising important questions, old and new. The answers will carry significant implications for our understanding of the scientific enterprise. The issue raised by William James in 1908 concerning the rational and empirical approaches is among those being reconsidered. Great philosophical problems often rise phoenix-like from their ashes to rekindle the fires of controversy.

Given the inspiration and guidance of James' efforts, I would like to pursue the issue of rationalism and empiricism further. However, the tools of thought I will employ will differ from James' philosophical speculation by examining the use of mythological discourse in science and religion, especially as it involves an understanding of how God is related to the world. What follows then is a serious flight of fancy that concerns a mutually fructifying encounter of reason and myth. This flight has as its destination a fuller understanding of the same questions that James included in his agenda. Let us hope that we arrive safely and on time.

Science has traditionally defended its rationalistic faith in the existence of "laws of nature," fixed, detectable, and intelligible patterns of regularity in the behavior of things. The success of mathematics in articulating such structures certainly has done nothing to daunt the faith of scientists. The tradition of such natural law is very long and deeply rooted. As heirs of ancient philosophy and medieval theology, those who subscribe to this position hold the common assumption that the *arche*, the undergirding structure of things, is the principle that generates and sustains the particular forms of order and connectedness, which are disclosed in scientific investigation (Hall 271). From its rationalist persuasion, science seeks to frame universal laws of an ever-increasing range of explanation from which more specific laws may be deduced. $E=Mc^2$ represents such a law. Here, truth is understood to be ultimately singular and unified. It is an account of things as members of one "all-inclusive fact," to use James' phrase.

Despite this heritage and commitment, many scientists readily admit that nature can also be approached on the empiricist's assumption that it is an aggregate of mostly independent events and things, which may best be described by inductive and statistical methods. Granted, very inclusive theories may still be derived from a broad analysis of the evidence, but these are of a weaker sort, having the odd feature of generally holding true for large populations while being powerless to predict the appearance or course of specific individuals. Thus, empiricism provides an account that emphasizes plurality and disconnectedness in this odd lot of a world.

Neither rationalism nor empiricism seems to provide a satisfactory explanation for the existence of order in the world. In their emphasis upon unity and lawfulness, rationalists classically have had difficulty in providing a sufficient understanding of the birth and growth of order within the whole of nature, since that whole cannot be understood unless it were already given in an ordered state. Perhaps this incomplete element in their program reflects an indebtedness to early theological assumptions. Empiricists too have experienced difficulty accounting for the presence of patterns of interaction and regularity to be found, even statistically, in a field of practically discrete, independent entities.

Fortunately, a third option, containing elements of both rationalism and empiricism as combined in a novel perspective, is coming to the fore in our own time. It is not a radically new approach. No idea is completely new. Most are recycled or reappear in appropriate historical situations. The various modern sources for this third position include especially revolutionary thought, philosophical pragmaticism, the process philosophy of Alfred North Whitehead, developments in information theory, in systems science, and in cybernetics, and the philosophical consequences of each as articulated by the likes of Bertalanffy, Jantsch, Laszlo, and Prigogine.

What does this muster of diverse names and schools have in common? Essentially, the vision of a universe in which all things grow, become, or emerge into ordered states or systems of true novelty on the basis of dynamic and creative interaction. All creatures are consequences of and contributions to their inclusive, dynamic environment. Biological evolution is nothing less than the process of interaction and change out of which is born processive ordering and progressive differentiation within and among natural systems. Whitehead sums it up nicely in his claim that the world labors as "a creative advance into novelty" (529).

The key to this third option, which I will call the systems-process view, is the bold assertion that all order is essentially negotiated order. It is neither given absolutely as a rationalist and stoic *logos*, nor is it a mere phantasmal effect of the war of all against all—the empiricist, existential chaos. Order itself is a creature, the consequence of the natural disposition or propensity of things to self-arrange through creative association over long periods of time. These creative associations provide for the emergence of complex patterns of regularity in nature at all levels of a great chain of being. Each individual thing is nested within a larger supportive and challenging communal context. In this set of circumstances it is both bounded and free, context-dependent and context-independent. Its behavior as context-dependent being lends itself to the rational approach. As a context-independent creature, it may be more easily portrayed in empirical categories. Order, of course, is the consequence of these mutual and complex affiliations between creatures that are reinforced and perpetrated as a tideway in the great stream of events we call nature.

Each philosophy of nature carries an implied theology or model of God within its logic. This is certainly true of both rationalism and empiricism, and we may speculate as well about the model of deity following from our third perspective of a processive, evolutionary world.

In the philosophy of rationalism, order is primary and identity is permanent, changeless. In empiricism, order is accidental regularity. Where it chances to arise, order is always subject to entropy and eventual dissolution. From chaos we arise and to chaos we shall return. In a theology for rationalists, God reigns supreme and eternal as the world-transcending monarch. He dictates law from a position beyond order or "out-of-order," while his creaturely subjects are condemned to be "in order." That is, they are subject to being plotted upon the grid of some preordained cartesian coordinate system. In the light of a rationalist theology, Abraham Heschel was correct: "All that exists obeys" (7). According to an empiricist's theology, *anarchai*, or numerous agents of decision and influence, frustrate order and fragment power. The result is a sort of everlasting feudal polytheism with its temporary alliances of mutual convenience in which no single sphere of order is dominant. The systems-process approach suggested here understands order to be the effect of spontaneity in nature that generates novel situations to which contextual adjustments are perpetually made. Order appears in self-reinforcing patterns of interactions that are always subject both to further modifications and to the emergence of additional, novel forms of interaction. Thus, order is not imposed on things as a matter of *archai* or principles and for the purpose of managing the barroom brawl of things among themselves. Nor is it merely apparent in the probabilistic behavior of things for whom relationships are temporary accidents or associations, of jostlings in a crowd. Instead, it is the ongoing pattern of "interexistence" (Laszlo 61), which emerges over time in the tideways of process.

And what model of divinity is implied in the systems-process view of nature? The act of cosmic creativity most familiar in Western culture is found in the biblical book of Genesis. I would claim that the biblical narrative provides for us not only a primal account but also a paradigmatic one quite in accord with the systems-process view. My contention is that philosophical and scientific models may benefit when correlated in a playful and adventurous way with myths. The result is a hybrid creature, a narrative with a reasoned structure. Efforts such as this occur all the time, mostly outside any awareness of the process and for the purpose of inserting human meaning and significance into purely objective, rational material. C. S. Lewis once described a child who regarded an unattractive porkchop on his plate as buffalo meat that he, a great Sioux warrior, had killed.. The meat became far more savory for having first been dipped in a story (Isaacs and Zimbardo 15). So it is with rational accounts when integrated with myth.

In the Genesis story, Yahweh calls the world into existence from the primordial abyss of wind-blown waters. Note that he does not work as a craftsman by shaping the world from some sort of preexisting material. Rather, he commands or orders it into being piece by piece, day by day, until the whole thing is completed. He calls order out of chaos. He separates the various from the undifferentiated. Light is separated from darkness, day from night, land from sea, and all manner of creatures from one another in a riotous proliferation of forms. As he commands these various constituents into existence, God renders decisions. He selects and differentiates. He builds an information-rich world by defining its multitude of creatures. His yea-saying to any one creature is simultaneously a nay-saying to all other possibilities in that situation. In his declarations, God confers a kind of definiteness on creation. Finitude, after all, is merely the exclusion of all alternatives save one.

It appears that God confers a binary texture upon his creation. "To be or not to be" is indeed the primordial question. Each answer to that question carries a single bit of information. The creation is built upon the countless instances in which that question is asked and answered.

We cannot simply ignore the delicate but perennial question of God's motive in creating the world. I suspect that the rationalist is most embarrassed by the problem. The creation after all is intelligible because its creatures conform to a reasoned order divinely imposed. But what order of reason does God in turn conform to in arriving at his original decision to create? The suggestion that God must have a reason, a justification, appears to compromise his omnipotence. The conclusion that he does not suggests that he acts in a capricious and arbitrary fashion. Theologians have therefore often concluded that God has reasons all his own, deep within his aseity—his self-distancing. But this is to say nothing at all since it divides reason into two species with no connection whatsoever, and *that* is unreasonable.

I would argue that an honorable model of God does not necessarily require that he be rational on all accounts. Indeed, the systems-process approach grants a qualified context-independent status to all creatures, great and small. How then can a similar status be denied God? God is God because he is the author of the primordial creative "posit," the first or original decision, based on nothing and *ex nihilo*, which provides the singular event from which all subsequent events take their bearings. This first act is the only event of pure spontaneity since it is based on no prior settled context and no a priori principle or *arche*. Indeed, the constitutive creative event is the one true act of anarchy! This, after all, is what theologians mean when they refer to "the divine sovereignty." God is constrained by nothing and hence it must follow that his initial act is radically free and spontaneous.

The primordial, divine posit becomes the context to which all further developments must respond. God provides the original bounds as well as the original orientation. Before God, all creatures coorient. This, indeed, is what it means to be a creature—to take one's bearing from God.

At this point, even the radically free and creative spirit of God discovers itself to be conditioned by the emerging complex system of the world. As is true with any artist, God is forced to adjust his later decisions to the conditions established as consequence of his earlier ones. The supreme context-independence that he enjoyed in his divine sovereignty at the moment of his original posit is replaced by the requirement that he reckon or negotiate with the community of his creation if he wishes to add further to it in a harmonious way. He therefore becomes, to some extent, context-dependent. God makes his contribution, to be sure, but so do his creatures.

Subtly yet surely, a mutual negotiated partnership, a coupling, emerges between God and his Creation. God becomes involved in the emerging order of the world. He is *the* One, but one among many (Huchingson 335). He plays along, so to speak, in the complex, dynamic interexistence of things in themselves. He discovers himself to be involved *in media res*, "in the middle of things," and he must adjust accordingly.

God's most privileged creature, humankind, is not neglected, or so we learn as we continue in the Genesis account. God deputizes one of his creatures, the human one, to manage the whole edenic territory. In a significant act of delegation, he instructs Adam to name each species of animal as it parades before him. More than an exercise in taxonomy is intended here. In the act of naming, Adam continues and completes the act of creation, of calling-to-be or yea-saying, for those animals so named, and the tacit nay-saying for those who were not actualized. These latter forms are destined forever to remain as rejected possibilities in the broader scheme of things. This mythological account suggests that the human species has a double vocation. It is *imago dei*, "in the image of God," in that it shares the divine capacity for free creation. Yet man is also *imago mundi*, "in the image of the world." Adam's creative posits are continually shaped and tested by the conditions imposed by a world in which he finds himself enmeshed.

Actually, all creatures share with mankind in this duplex character of being context-independent and context-dependent. The difference is, of course, a vast matter of degree, and that is important. Still, "there is a freshness deep down things," just as the poet says. This freshness is the universal spontaneity that is present in all creatures in some primitive measure.

This is a mythological and not a literal speculative excursion into the model of God suggested by a world of process and emergent order. Myths continue to influence thought as part and parcel of our conceptual framework. They are powerful and often underrated tools of the human mind. Whether we like it or not, great myths of our heritage continue to inform our understanding of the human enterprise, even the enterprise of science whose practitioners once thought that they had safely escaped inclusion in any myth. In keeping with the theological myths of rationalism, Kepler could claim that the object of science is to think God's thoughts after him. The myth of empiricism declared that, with the disappearance of order in the multiplicity of things, chaos replaced order and rendered the idea of a necessary structure incoherent. The world was left to the many gods of polytheism and one suspects that even these are superfluous. For in the end, the provincial orders established by competing outlaw gods are in perpetual isolation and conflict and hence constitute a kind of chaos in themselves.

The third model we have suggested, the model of process of the negotiated emergence of order, permits both order and spontaneity to exist along a spectrum that ranges from pure context-independence (the state of absolute original deity) to pure context-dependence (the state of absolute creatureliness). The rational-empirical methods of science succeed simply because the world may be genuinely characterized as both ordered and free, connected and disconnected. Science is therefore not merely an unfolding of fixed and eternal laws through a process of educated and ingenuous guessing. Nor is it some King Midas project of supplying order where none is really given. It is both the act of discovery *and* the genuine act of creation.

List of Works Cited

Hall, David H. "Process and Anarchy: A Taoist View of Creativity." *Philosophy East and West* 28 (1978), 270-285.

Heschel, Abraham. *Who Is Man?* Palo Alto, Ca.: Stanford University Press, 1965.

Huchingson, James. "The World as God's Body: A System's View." *Journal of the American Academy of Religion* 48 (1980), 335-344.

Isaacs, J. and N. Zimbardo, eds. *Tolkein and His Critics.* South Bend, Ind.: University of Notre Dame Press, 1968.

James, William. *Essays in Radical Empiricism and a Pluralistic Universe.* Ed. R. B. Perry. New York: Dutton, 1971.

Laszlo, Ervin. *The Inner Limits of Mankind.* New York: Pergamon, 1978.

Whitehead, Alfred North. *Process and Reality.* Eds. D. R. Griffin and D. W. Sherburne. New York: MacMillan, 1978.

The Inside of the Human Outlook: Creativity in the Humanities and Herman Melville

Daniel C. Noel

For the sake of brevity let me propose baldly, as a three-part premise, something I am unable to support with historical or philosophical argumentation: that what the humanities give us when they are trying to be the humanities—and not, say, the social sciences—is a view of the world that intentionally includes the human who is doing the viewing. Furthermore, the humanities seek empathetically to understand the subjective experience of a human being involved in viewing, and to some extent changing, the external world. Finally, in this task the humanities, inevitably informed by the concrete images of literature and other expressive media, are dependent upon the arts in a way they are not upon the sciences. The "method" by which the humanities seek understanding operates most purely, for the humanities' own distinctive purposes, in the creative imaginings of artists—if only of the inferior artist lurking within the humanist scholar. It is there that the humanities properly find the paradigmatic expressions of what I would call the inside of the human outlook.

This no-doubt debatable premise allows me to suggest the significance of some insights I want to draw from the imaginings of a decidely *superior* artist: Herman Melville. Melville was the subject of my doctoral dissertation two decades ago and continues to influence me as an interdisciplinary humanist. His images reveal creativity at work; through them he imagines the imagination as a concrete activity, thereby instructing the humanist in the operations underlying his own most constitutive concerns. My hope is that these insights may also prove helpful in illuminating the creative process for scientists.

> We are off! The courses and the topsails are set; the coral-hung anchor swings from the bow; and together the three royals are given to the breeze that follows us out to sea like the baying of a hound. Out spreads the canvas—alow, aloft—boom-stretched on both sides with many a stun 'sail, till like a hawk, with pinions poised, we shadow the sea with our sails and reelingly cleave the brine.
>
> (*Mardi; and a Voyage Thither* 3)

These are the opening lines of Melville's third novel, *Mardi* of 1848, a wildly allegorical romance and a kind of test-flight for *Moby-Dick*, which was to follow in three years. Melville's first two novels, *Typee* and *Omoo*, had been narratives based largely on his actual experiences in Polynesia (although they were racy enough to cast doubt on their author's veracity). *Mardi* was to have been a similar travel narrative, but Melville changed his plans. As he explained in a letter,

> I have long thought that Polynisia furnished a great deal of rich poetical material that has never been employed hitherto in works of fancy; and which to bring out suitably, required only that play of freedom & invention accorded to the Romancer & poet—However, I thought, that I would postpone trying my hand at any thing fanciful of this sort, till some future day . . . Well: proceeding in my narrative of *facts* I began to feel an incurable distaste for the same, & a longing to plume my pinions for a flight, & felt irked, cramped & fettered by plodding along with dull common places,—so suddenly abandoning the thing alltogether, I went to work heart & soul at a romance which is now in fair progress, since I had worked at it under an earnest ardor. (*Letters* 70-71)

In these images of soaring, Melville fuses the voyage *in* his novel and his ambitions as he writes *of* it. Late in the pages of *Mardi*, one of the main characters describes the mysterious work of a legendary author named Lombardo. Clearly it is a self-description by Melville as well:

> . . . like eagles, his thoughts were first callow; yet, born plumeless, they came to soar. . . . When Lombardo set about his work, he knew not what it would become. He did not build himself in with plans; he wrote right on; and so doing, got deeper and deeper into himself; and like a resolute traveler, plunging through baffling woods, at last was rewarded for his toils. "In good time," saith he, in his autobiography, "I came out into a serene, sunny, ravishing region; full of sweet scents, singing birds, wild plaints, roguish laughs, prophetic voices. Here we are at last, then, " he cried; "I have created the creative." (*Mardi* ch. 169, 557)

Unfortunately, Melville's craft was not yet equal in *Mardi* to the great imaginative flight he wished to make, and his portrait of Lombardo's creative breakthrough is perhaps more an accurate picture of his achievement in *Moby-Dick* than here in *Mardi* itself. There is evidence that Melville knew he was getting ahead of himself in attempting the vast allegorical exploration of *Mardi*, but that he felt it was worth the risk of artistic failure. In a speech by *Mardi*'s narrator-hero, the literary voyage is compared to a Columbian quest for the New World:

> But this new world here sought, is stranger far than his, who stretched his vans from Palos. It is the world of mind; wherein the wanderer may gaze round, with more of wonder than Balboa's band roving through the golden Aztec glades.
>
> But fiery yearnings their own phantom-future make, and deem it present. So, if after all these fearful, fainting trances, the verdict be, the golden haven was not gained,—yet, in bold quest therof, better to sink in boundless deeps, than float on vulgar shoals; and give me, ye gods, an utter wreck, if wreck I do. (*Mardi*, ch. 169, 557)

Later, in a letter to a publisher, Melville defended his writing of *Mardi* by saying that "some of us scribblers, My Dear Sir, always have a certain something unmanageable in us, that bids us do this or that, and be done it must—hit or miss." He also made the claim that "it is better to fail in originality than to succeed in imitation. He who has never failed somewhere, that man can not be great. Failure is the true test of greatness" ("Hawthorne and His Mosses," Leyda 412).

After *Mardi*, under the pressure of financial need, Melville wrote two novels, *Redburn* and *White Jacket*, which represent in most respects a return to conventionality. But then came *Moby-Dick*, and the imaginative powers tested earlier were wedded to careful craft to produce what many critics would acknowledge is the veritable Great American Novel. Two major influences prompting Melville to "plume his pinions" for another flight in *Moby-Dick* were his rereading of Shakespeare and his meeting Nathaniel Hawthorne, a neighbor in the western Massachusetts hills in 1850 and 1851.

Finding a seven-volume edition of Shakespeare with large type appropriate for his weak eyes, Melville went through the plays enthusiastically, marking the passages that most struck him. One of these was Theseus' famous disquisition on the imagination in *A Midsummer Night's Dream*. Melville sidelined the following portion of it (Cowen 106):

> The lunatic, the lover, and the poet
> Are of imagination all compact.
> One sees more devils than vast hell can hold.

Here Melville's sidelining stops, but the speech, of course, continues:

> That is the madman. The lover, all as frantic,
> Sees Helen's beauty in a brow of Egypt.

The poet's eye, in a fine frenzy rolling,
Doth glance from heaven to earth, from earth to heaven.
And as imagination bodies forth
The forms of things unknown, the poet's pen
Turns them to shapes, and gives to airy nothing
A local habitation, and a name.

Melville has not only indicated here a conscious concern for the idea of the imagination but has especially highlighted his interest in the *lunatic* as a figure possessing this faculty. Moreover, in some cryptic notes he left on the fly-leaves of volume vii of his set of Shakespeare there is this fragment: "Madness is undefinable—It and right reason extremes of one." The strong possibility is that, by way of Kant, Coleridge, and Carlyle, Melville's "right reason" was equivalent in his mind to Shakespeare's notion of the imagination. This would mean that for Melville madness and imagination were aspects of the identical mental orientation.

Melville's growing sense of the closeness of failure and madness to the life of the imagination was underscored at about this time by the news that a long-time literary acquaintance had, as the journal *The Literary American* publicly and coldly phrased it, "become deranged." Melville then shared his reaction to this news with another friend:

> Poor Hoffman—I remember the shock I had when I first saw the mention of his madness.—But he was just the man to go mad—imaginative, voluptuously inclined, poor, unemployed, in the race of life distanced by his inferiors . . . without a port or haven in the universe to make. . . . This going mad of a friend or acquaintance comes straight home to every man who feels his soul in him,—which but few men do. For in all of us lodges the same fuel to light the same fire. And he who has never felt, momentarily, what madness is has but a mouthful of brains. (*Letters* 83)

In this, as in the other passages cited, I think we can see and feel Melville's imagination *in action*, even when he is giving us insights that refer reflexively to the imagination at work in his own art. And another facet of this self-referring character of his writing here is that he uses concrete sensual images: words denoting physical objects and processes applied metaphorically to immaterial or psychic realities. This, too, is part of what the creative imagination is all about, for as Shakespeare taught Melville it *bodies forth* the forms of things unknown, reinforcing the connection of the human viewer to the body and the physical world . In addition, the logic of the imagery tells us that whoever "feels his soul in him" will be able to empathize with the madness of a friend. In other words, the imagination allows us to feel our soul within us and thereby feel what madness is. With such insights, I think we are starting to see how the humanities might help the sciences to understand the creative process, but we need to pursue a bit further the images of Melville's life and work.

In the summer of 1850 Melville met Nathaniel Hawthorne and wrote a highly favorable review of a collection of the latter's tales. Melville commented on the "boundless sympathy with all forms of being" displayed by Hawthorne's prose, especially in its more melancholy moods. "And we see," Melville went on, "that suffering, some time or other and in some shape or other—this only can enable any man to depict it in others" ("Hawthorne and His Mosses," Leyda 404). Suffering, like failure or the sense of one's soul within one that grants a feeling of what madness is, seems to be linked with the imagination for him. Elsewhere in his review (using the same wording at one point: "in some shape or other") he speaks in an oft-quoted discussion of that "touch of Puritanic gloom" or "power of blackness" in Hawthorne, which he claims "derives its force from its appeals to that Calvinistic sense of Innate Depravity and Original Sin, from whose visitations, in some shape or other, no deeply thinking mind is always and wholly free" (406). Melville is very careful not to make a simple affirmation of the abstract church doctrines of "Innate Depravity" and "Original Sin"; indeed, his capitalizations perhaps suggest that he was wary of their abstractness. He has earlier employed two very sensuous images—"gloom" and "blackness"—to introduce the insight, and his elaboration speaks of a "sense" from whose "visitations," in *some* shape or other (like suffering) no *deeply thinking mind* is *always* and *wholly* free. These qualifications stress that Melville was probing for the living experience more accurately conveyed by imaginative metaphor than by the logical distinctions of Christian dogma. "At all events," he concludes, "perhaps no writer has ever wielded this terrific thought with greater terror than this same harmless Hawthorne" (406).

One of the things Melville liked best about Hawthorne, one of the things about him that inspired Melville to complete *Moby-Dick*, was Hawthorne's resemblance to Shakespeare, another writer Melville felt was capable of wielding "terrific" thoughts with great terror. Melville's review treats Hawthorne as an American Shakespeare, while saying of the latter that "through the mouths of the dark characters of Hamlet, Timon, Lear, and Iago, he craftily says, or sometimes insinuates, the things which we feel to be so terrifically true that it were all but madness for any good man, in his own proper character, to utter, or even hint of them. Tormented into desperation, Lear the frantic king tears off the mask, and speaks the sane madness of vital truth" (407).

The sane madness of vital truth, the moments of clear vision that bring with them terror and the threat of madness (or a temporary submersion in madness), as well as a sensitivity to suffering and failure in many forms—all this Melville's imagination was able to convey in the novel he said was "broiled" in "hell-fire." Writing to fellow novelist Richard Henry Dana, he shared the challenge he met in creating *Moby-Dick*:

> It will be a strange sort of book . . . I fear; blubber is blubber you know; tho' you may get oil out of it, the poetry runs as hard as sap from a frozen maple tree;—& to cook the thing up, one must needs throw in a little fancy, which from the nature of the thing, must be ungainly as the gambols of the whales themselves. Yet I mean to give the truth of the thing, spite of this. (*Letters* 106–108)

He gave the truth of the thing by cooking it up with a little fancy and broiling it in hell-fire, and here again we find the close relation between the imagination's work and the vision of the Shakespearean lunatic who sees "more devils than vast hell can hold." Tempting the fires of madness was, for Melville, the means by which the imagination produces our most accurate account of the experience of the world, the truth as human beings actually live it and the humanities try to understand it, the *vital* truth, the inside of the human outlook. This prize of the imagination, framed in danger, was in contrast to the safe and shallow truths of the intellect's devising, the detached cognitive pronouncements of those who possessed "but a mouthful of brains."

The dialectic of danger and timidity in the search for the truth of life is given fullest imaginative expression in chapter 96 of *Moby-Dick*. Here Melville depicts the "try-works" of the whale-ship, the huge vats in which the blubber is boiled into valuable sperm oil—and where, by implication and imagery, poetry is created from the raw material of Melville's experience. The picture presented in chapter 96 is particularly hellish since it shows the try-works in fiery operation during a moonless night. The fires of the try-works were so terrifying to Melville that he warned the reader not to look into them too long: *permanent* or *complete* madness was not a requirement of the Melvillean imagination. "Give not thyself up, then," he writes, "to fire, lest it invert thee, deaden thee; as for the time it did me. There is a wisdom that is woe; but there is a woe that is madness." In *Moby-Dick* Melville surely champions the wisdom that is woe, the wisdom issuing from an imagination that has tempted and tasted madness. But to achieve this vital truth it is necessary to draw on one's woe sanely, creatively, making use of madness without succumbing to it entirely. This is the synthesis Melville sought to body forth in an image at the close of chapter 96 that hearkens back to the language of his ambitions for *Mardi* three years earlier:

> And there is a Catskill eagle in some souls that can alike dive down into the blackest gorges, and soar out of them again and become invisible in sunny spaces. And even if he for ever flies within the gorge, that gorge is in the mountains; so that even in his lowest swoop the mountain eagle is still higher than other birds upon the plain, even though they soar.
>
> (*Moby Dick* 419)

Melville meant to "plume his pinions" for a flight in *Mardi;* "like eagles," as he wrote of the archetypal author Lombardo in that novel, "his thoughts were first callow; yet, born plumeless, they came to soar." The preparations for soaring flight made in *Mardi* came to culmination in the Catskill eagle and other images of *Moby-Dick*. The later novel fulfills a dark promise offered up by the earlier one: "He knows himself and all that's in him, who knows adversity. To scale great heights, we must come out of lowermost depths. The way to heaven is through hell" (*Mardi* ch. 180, 594)

As an academic humanist, I would submit that the necessary daring of the darkness, the requisite encounter with the hell-fires, may come not only through what Melville sardonically called the happy accident of personal adversity—imaginative creativity being evoked "as bronze was discovered by the melting of the iron and brass at the burning of Corinth." It may come through humanistic understanding at many levels, so that while a Melville reader, for instance, becomes sensitized to, and able to draw upon, personal woe, it also seems likely to me that the force of Melville's imagination, given a decently responsive reader, is sufficient to convey something of Melville's suffering—and with it something of Melville's grasp of vital truth. This is how I read his statement that only someone who has suffered can have access to the imaginative resources for depicting it in others. It is as if the imagination of a Melville not only creates its own embodied meanings but also propagates itself, as it were, in the mind of the reader.

And I see this process as generally true of involvement in the humanities. After all, Melville's words were that the suffering must be "in *some shape* or other," which again implies that by attending to the creative energies of the imagination, exemplified in what Shakespeare referred to as the *shaping* pen of the poet, the humanities may be able to show us in an edifying fashion that nothing in the human outlook is alien to us, that there indeed lodges within us "the same fuel to light the same fire." Moreover, the creative process as exercised and elucidated in a reading of someone like Melville must help lead toward that "boundless sympathy with all forms of being" that he noted in Hawthorne and went on to relate to suffering. Sympathy, or empathy: the pathos or feeling of involvement with the world one is viewing, the world that starts with one's own body and extends out to embrace the whole of creation. This feeling-with and feeling-for, fostered to a greater or lesser degree by the activities of the humanities as these are grounded in the creative imagination, seems to me a worthy model to hold up for scientists to consider and compare with their own kinds of creativity.

List of Works Cited

Cowen, Wilson Walker. "Melville's Marginalia." Unpublished doctoral dissertation, Department of English, Harvard University, 1965.

Melville, Herman. "Hawthorne and His Mosses"; rept. in J. Leyda, ed., *The Portable Melville*. New York: Viking, 1952, 400-421.

———. *The Letters of Herman Melville*. Eds. Merrell R. Davis and William H. Gilman. New Haven: Yale University Press, 1960.

———. *Mardi; and a Voyage Thither*. Ed. H. Hayford, H. Parker, and T. Tanselle. Evanston and Chicago: Northwestern University Press and the Newberry Library, 1970.

———. *Moby-Dick; or the Whale*. Eds. H. Hayford and H. Parker. New York: Norton, 1976.

Noel, Daniel C. "The Portent Unwound: Religious and Psychological Development in the Imagery of Herman Melville, 1819-1851." Unpublished doctoral dissertation, Drew University, 1967.

Keynote Address

Modern Science and Pantheism

Harold J. Morowitz

Last summer I journeyed to the desert of Sinai to climb the mountain where Moses is said to have stood and received the word of God. While the ground did not quake beneath my feet, my feet quaked upon the ground in the realization that regardless of one's religious beliefs, in standing on those rocks, one was commemorating a covenant between God and man that had spiritually energized the Western world for over three thousand years. I was also acutely aware that from 1600 to 1900 Western man, following the lead of the scientific establishment, had broken the covenant, leaving us "alone and afraid in a world we never made." What was less clear from the mountain was my personal Sinaic vision that Western man has, since 1900, been forging, under the leadership of science, a new covenant with a god far different from the jealous deity who enshrouded the mountain in dark clouds.

The new covenant, unlike the old, is not emerging in a single encounter; rather it is growing gradually from the experiences of individuals who seek to understand the world. Just as it took about three thousand years to breach the original contract, the growth of the new agreement has occurred over a long period of time. Nevertheless, I believe that a novel world view, a new understanding of our relation with the universe is upon us. It is very difficult to see with clarity this grandiose development because we are in the midst of it.

What we are discussing is the ascendancy of God, the waning of God, and the rebirth of god. The subject matter is so awesome that any attempts in this direction seem tinged with hubris. But if these matters are vital to human existence and human happiness, then we must proceed.

What we have called the old covenant is not a single document, for the Judaeo-Christian tradition has from its earliest days fragmented into major and minor divisions, each with varying theological beliefs. There are, however, common elements of these beliefs that place them within the old covenant. First there is the tenet that a personal god or some non-human representative of God communicates the "Word" to one individual or a small group of individuals. The second assumption is that this "Divine Word" is then interpreted by individuals or by officials of the particular faith.

The reason that the old covenant has so many forms is that different groups accept different revelations as valid. How one knows a true revelation from a false always stands as an open issue, one that has often led to conflict and death in the history of Western civilization.

Belief in a real divine revelation is usually acquired through a leap of faith or through historic tradition. Thus Judaism's scriptures come from Moses on Sinai, Christianity's from the life, death, and resurrection of Jesus as reported by the Apostles, and Islam's from the Word of God delivered to the prophet Muhammed by the Angel Gabriel. Within the old covenant this tradition of revelation continues. Thus Mormonism was started in 1827 when Joseph Smith Jr. received the word on golden plates from the Angel Moroni.

What is common to various views of the old covenant is a personal God who interacts with mankind and communicates directly or through angels. Ethics and rules of behavior come directly from the scriptures; they are God-given. This view in one form or another came to dominate the Western world.

The original convenant of the Jews appears to have survived the first one thousand years or more with no record of philosophical question until Athenian philosophy carried by the legions of Alexander of Macedon penetrated the Near East. Aristotle, tutor of Alexander, formulated a theology based on physics, for his god, postulated by reason rather than directly known, was the "unmoved mover," the eternal immaterial source of motion in the universe. Such a concept of god is so radically different from the usual religious view that it is only by convention that the same word is used. The two views of the deity finally came into intellectual confrontation under equal terms in the city of Alexandria where communities of Hebrews and Hellenists lived side by side in relative tranquility.

The first recorded attempt to rationalize the God of Sinai with the god of Aristotle appears in the work of an Alexandrian Jew, Aristobulus of Paneas, whose writings in the second century B.C.E. attempted to use the method of allegory to make the very anthropomorphic God of the Old Testament consistent with the god of the Greek philosophers. The most influential synthesis of Hebrew and Greek philosophy was the work of another Alexandrian, Philo Judaeus (20 B.C.E.-40 C.E.). Even though the old covenant held firm from Philo till 1600, there was a constant necessity to assert the dominance of faith (the old covenant) over secular knowledge. This can be seen in the writings of Averroes (ibn Rush'd) 1126-1198. From his work, later Averroists were able to extract the doctrine of double truth by which contrary doctrines from philosophy and theology were both true. The rediscovery of Greek philosophy by Islamic scholars created problems because the mode of knowledge open to philosophy and ultimately to science was different from knowledge by faith, which was central to the old covenant. And indeed it is the fundamental epistemological difference in knowledge by private faith and knowledge by the public methods of science that has been the core of almost a thousand years of conflict. The problem was addressed by Maimonides (1135–1204) within the Jewish tradition, by St. Thomas Aquinas (1224–1274) within the Christian tradition, and by many others. In every case, the scholars of the Middle Ages turned to knowledge by faith as the ultimate truth.

The beginning of the break with the old covenant in the sixteenth and seventeenth centuries was sharp and at times brutal. It may best be illustrated by the lives and thoughts of Giordano Bruno, Galileo Galilei, and Benedict Spinoza. Bruno (1548–1600) was burned to death by Venetian Inquisitors, who had kept him jailed for nine years. His religious beliefs are summarized in the following paragraph from the *Encyclopedia of Philosophy*:

> He conceived of God as the imminent cause or goal of nature, distinct from each finite particular only because he includes them all within his own being. The divine life which informs everything also informs the human mind and soul, and the soul is immortal because it is part of the divine. Since God is not distinct from the world, he can have no particular providential intentions. Since all events are equally ruled by divine law, miracles cannot occur. Whatever happens, happens in accordance with law, and our freedom consists in identifying ourselves with the course of things. The Bible, according to Bruno, insofar as it errs on these points, is simply false.

Galilei (1564–1642) dissociated physics and philosophy and developed an independent epistemology of physics. Although he did not engage in theological discussion, the Church of Rome was aware of the threat of the new independent source of knowledge of man's place in the universe. After several go-rounds with the Inquisitors, Gallilei spent the last eight years of his life under house arrest because of his support of the Copernican system of astronomy. In retrospect, the Vatican was perceptive in recognizing the heretical potential of an independent method of acquiring knowledge of man's place in the universe.

Benedict Spinoza, (1623–1677) like Bruno and Galilei, paid a price for his philosophical beliefs. He was excommunicated by the Jewish congregation of Amsterdam and lived under the knowledge that his heresies might be punished by the broader community. Yet this heretic has come to be known as "the god intoxicated philosopher of Amsterdam." His heresy was to identify god and nature as being synonymous, thus breaking with the old covenant, which placed God outside of nature. The difference is great, for Spinoza allowed no miracles, which to him would have constituted God breaking his own laws. Struggling to reconcile god and God, he also regarded the Bible as an allegorical attempt to provide for the common man a truth that could be probed to its metaphysical core only by philosophers.

The towering scientific figure in the seventeenth century was Isaac Newton (1642–1727). His formulation of the laws of motion and his demonstration of Kepler's laws of planetary motion from first principles were demonstrations of the exact laws of god as envisioned by Spinoza. Adherents of the old covenant thought Newton's law to be unequivocal demonstration of their God.

> Nature and Nature's Laws lay hid in night;
> God said, Let Newton be! and all was light.
>
> Alexander Pope, "Couplet in Honour of Newton"

Thus began a one-hundred-and-fifty-year movement to demonstrate the existence and beneficence of the old-covenant God from the beauty, precision, exactness, and necessity of the newly emerging sciences. That movement reached its peak in the Bridgewater Treatises. These works have now passed into obscurity, but we include a description of them taken from the *Catholic Encyclopedia*:

> *Bridgewater Treatises:*—These publications derive their origin and their title from the Rev. Francis Henry Egerton, eighth and last Earl of Bridgewater who, dying in the year 1829, directed certain trustees named in his will to invest in the public funds the sum of £8,000, which sum with the accruing dividends was to be held at the disposal of the president, for the time being, of the Royal Society of London, to be paid to the person or persons nominated by him. It was further directed that those so selected should be appointed to write, print, and publish one thousand copies of a work: "On the Power, Wisdom and Goodness of God as manifested in the Creation, illustrating such work by all reasonable arguments, as, for instance, the variety and formation of God's creatures, in the animal, vegetable and mineral kingdoms; the effect of digestion and thereby of conversion; the construction of the hand of man and an infinite variety of other arguments; as also by discoveries ancient and modern in arts, sciences, and the whole extent of modern literature.

Curiously, these treatises had a reverse effect of that intended by Reverend Egerton, for they enhanced the theological status of science which then came into sharp conflict with Christian theology following Darwin's exposition of evolutionary theory. The influence of Darwinism led to a secularization of the Western intellectual world and led finally to the "death of God" theology of the mid-nineteen hundreds.

The arguments of the Bridgewater Treatises were part of the tradition that went from Aristobulus to St. Thomas to early nineteenth-century England. For the god of the Bridgewater Treatises is the god of Aristotle and the god of Spinoza embodying all of nature and the laws of the universe. The series argued for the god of argument from design (given a complex structure it must have a designer). It was a good argument, offered by brilliant and serious scholars, but it failed because the method of Aristotle can never lead to the God of Sinai.

The scientific establishment reacted to the impact of Darwin's findings by rejecting all notion of God and withdrawing into the agnosticism of Thomas Huxley and others. And so nineteenth-century science ended in a materialism summed up in the words of physiologist Emil duBois-Reymond:

> nevertheless, if our methods only were sufficient, an analytical mechanics of the general life process would be possible. This conviction rests on the insight . . . that all changes in the material world . . . reduce to motions. Therefore even the life process cannot be anything but motions . . . the processes within the organic state must ultimately be reducible to such simple motions . . . if the difficulty of analysis did not exceed our ability, analytical mechanics fundamentally would reach even to the problem of freedom of the will.

In rejecting the God of Bishop Wilberforce, the scientific community also unthinkingly rejected the god of Aristotle and Spinoza, the god of design. Biologists spent a long time in this officially agnostic position, but events in physics were following a different path. The developments in quantum theory, relativity, and, ultimately, information theory and statistical mechanics forced scientists to reintroduce the human mind as a primary focus in understanding the universe. The human mind, which had become curious epiphenomenon in the previous quotation from duBois-Reymond, returned to its central position because of specific requirements of the new physics.

The revolutionary physics was not seen as lacking philosophical and religious significance by its founders. There was an outpouring of philosophical writings by the founders of the new science. In discussing the laws of physics, Max Planck wrote that they "exhibit a rational world order" thus demonstrating "an omnipotent reason which rules over nature." Werner Heisenberg also developed sympathy with the god of reason, the god of the Greek philosophers. Erwin Shrödinger turned to the Vedantic vision, the world mind. Albert Einstein spoke of believing in the god of Spinoza. Referring to the religion of a scientist he wrote:

> His religious feeling takes the form of a rapturous amazement at the harmony of natural law, which reveals an intelligence of such superiority that, compared with it, all the systematic thinking and acting of human beings is an utterly insignificant reflection. This feeling is the guiding principle of his life and work, insofar as he succeeds in keeping himself from the shackles of selfish desire. It is beyond question closely akin to that which has possessed the religious geniuses of all ages.

The challenge to the materialism of late nineteenth-century biology was slower in coming and arrived from more peripheral perspectives. Henri Bergson, biology student turned philosopher, published *Creative Evolution* in 1907. He identified the *élan vital*, the vital impetus of evolution itself as a supra-consciousness, a god who moved biological development in the way that Aristotle's god moved the planets. This theme was later taken up by Teilhard de Chardin, who spent a lifetime trying to reconcile the god of evolution with the God of Golgotha. He wrestled with the same difficulties that St. Thomas had encountered six hundred years earlier.

In 1913, Harvard physiologist Lawrence J. Henderson published an extraordinary book, *The Fitness of the Environment*. After fifty years of Darwinism, Henderson examined the other side of the coin and argued that fitness was a reciprocal relation between organism and environment, Drawing on all of the available science of his day, he reinforced the scientific basis of the argument from design to present it in its strongest possible form. I am surprised that Henderson's work has not been adequately remembered over the years, for it was an answer within science to the total rejection of the very concept of purpose by the scientific community.

The seventy years since Henderson's work have produced such a wealth of scientific advances that it is difficult to keep up with them and incorporate a broad view of science in our philosophy. A few rather overwhelming points have emerged. First the triumph of the Big Bang theory has made the notion of a beginning and an end as much a part of science as they have always been in Western religion, except that the time scales are so vastly different as to make comparisons meaningless. Second, a vast wealth of scientific details leads up to the notion that life is a property not of isolated organisms in an environment, but an integrated property of the planet itself. James Lovelock has suggested this in his Gaia hypothesis, and I will present the detailed argument in my forthcoming book, *Earth, Air, Fire and Water*. The bottom line is that our understanding of molecular biology, ecology, geophysics, meteorology, and hydrology now makes it clear that the detailed working of all the features of our planet is necessary for continuing life. This lends great force to the argument from design and urges us one step further. The precise workings of all the different components to make possible intelligent life on earth suggest that the plan of the universe somehow had us in mind.

The new pantheism reasons from science to a cosmic intelligence that is not unrelated to our existence. I realize I have not here presented the scientific details, but I assure you that they exist and do provide the coherent basis for a design far more intricate and interrelated than even the view put forth by Henderson. We never again need be strangers in our world. Modern physics has made our minds an important creative element of the world, and contemporary earth sciences have immeasurably reinforced the argument from design.

To the hard-nosed materialists in the Huxley-Haekel tradition, this forces you to take seriously the god you wanted to eliminate. To the nature lovers, this makes you and your surroundings part of a coherent whole. To the Buddhists, this provides the scientific background of your existence as parts of a cosmic process of which you are a local manifestation. To those of you who follow in the many post-Sinaic covenants, we cannot within science find the God of revelation. We can see more clearly emerging the god of Spinoza who is to be worshiped by understanding his universe. For two thousand years since Aristobulus, thinkers have struggled to merge the god of reason and the God of revelation. The failure to achieve that synthesis speaks to the difficulty of combining concepts with different epistemological bases, with different views of reality. Nothing within science argues against the God of revelation unless those revelations contradict the laws of nature, yet nothing within the argument from design leads to the God of revelation.

If I trembled on Sinai it was because of this troubling knowledge that the God of our fathers is not the god of design. If I rejoiced on Sinai it was because of the knowledge that the cosmos and you and I are not strangers, but we are somehow joined in a web of divine law that is a global affirmation. That may not solve our problems, but it gives us the strength to look for creative solutions.

Panel Topic

Case Studies and Personal Accounts

Creativity in Medicinal Chemistry and Biochemistry

Alfred Burger

The principal mission of medicinal biochemists is to discover, design, develop, and understand new therapeutic agents. Identifying seminal "lead" compounds is their most challenging problem since every experience and idea in biology and chemistry bears on finding potentially successful and defendable therapeutic inroads. Medicinal chemists study natural products of alleged therapeutic activity, synthesizing them if the state of the art permits, or if possible devising a novel way of obtaining them. They also prepare thousands of synthetic compounds for biochemical and biological evaluation. Some medicinal chemists study the metabolism of drugs and the mechanisms by which drugs and other biologically active compounds act. In all these efforts, a mutual transfer of ideas and experiences from biology to chemistry is needed. I want to present examples from my own work to demonstrate this process.

It has been my experience that no clear division exists between creativity and invention except that invention involves practical results while creativity is an intellectual process with or without apparent practical ramifications. In either case, before a problem is tackled, one has to be completely familiar with all previous work that is relevant since one hour in the library can save weeks or even months of unprepared laboratory work. Large literature searches are now aided by automated and computerized searches of abstracts journals, but the personal evaluation of such surveys can differ widely and a comprehensive library search for a compound's reactions and uses in some other area of science often outlines a bigger problem than one can attempt to study. Then it takes individual or committee deliberation to choose a more compact area to be studied. The decision to reduce unwieldy problems to manageable size is one of the first steps in scientific creativity, preceded only by the more systematic decision whether one should enter a particular field of research at all.

My first post-doctoral researches at the University of Virginia concerned the modification and simplification of the molecular formula of the opium alkaloid, morphine. Drug addiction existed also sixty years ago, and all sociological efforts to curb it had failed. Our task was to separate the medicinally invaluable analgetic properties from the disturbing euphoric side effects that lead to drug craving and dependence. The chemical structure of morphine has many features, but we concentrated on combinations of three of them: a basic system of condensed rings of atoms, a hydroxyl (OH) group, and an amino group, NR_2. Compounds containing hydroxyl and amino groups are called aminoalcohols. This type of structure is encountered in many neurohormones and plant alkaloids.

After making over 150 of such aminoalcohols containing condensed ring systems, we decided to simplify the structures further. We started with cyclohexanone, a compound with one hexagonal system of six carbon atoms, and with a suitable reagent, we added one more carbon atom, on the outside of the stable hexagonal ring. This yielded an epoxide that was converted to aminoalcohols by a simple procedure. The yield was small, and when I concentrated the remaining reaction liquids an oil was left behind that analyzed for one carbon and two hydrogen atoms more than in cyclohexanone. A search of the literature indicated that the oil was cycloheptanone, a seven-membered ring homolog of cyclohexanone. It seemed unlikely that this could be true because no reagents were known that could expand a stable ring of carbon atoms. But there it was, and we published our paper with a rather lame explanation of how the reaction might have gone.

Cycloheptanone at that time was very difficult and tedious to come by, and our method offered a welcome shortcut for its preparation. The British chemist Sir Robert Robinson seized upon this advantage when he needed cycloheptanone in an unrelated study of atropine and cocaine. While he was at it, he came upon an explanation of our ring expansion on the basis of a new electronic theory he had proposed.

Many discoveries in medicinal chemistry are thus made either by accident or by serendipity. To alert oneself to chance discoveries one has to have, as Pasteur put it, a prepared mind. One has to oberve carefully, have a good imagination, be intellectually agile, and have persistence. If a chance result occurs, one has to evaluate it objectively but keep an open mind to accept courageously the sometimes unexpected observed facts. Obviously, such an event demands an explanation, and solving the riddle involves creative thinking.

Serendipity is a term coined by Horace Walpole in 1754. It is based on a fable about two princes of Serendip (Sri Lanka) who made unexpected discoveries while looking for something else. One example occurred when they traveled along a road and saw that the grass had been eaten only on the left side although it looked less appetizing than that on the right. Finally, they found out that a mule blind in the right eye had passed along that road before them. In medicinal research, serendipity arises when one sets out to do one thing and finds another.

The way we invited serendipity then was to do many experiments, hoping that one of them would produce the desired results. This is the path taken in drug screening; it is in itself not creative. It is wasteful, but it remains as the only way if no other rational selection can be made. This kind of drug development has found its greatest exacerbation in the synthesis and testing of tens of thousands of compounds: 10,000 for antituberculous agents, 10,000 sulfanilamide derivatives, 10,000 penicillins, and 250,000 compounds as candidate anticancer agents. Equally many thousands of compounds have been screened as local anesthetics, antispasmodics, antihistaminics, and analgetics, as well as for antidepressant, antianxiety and antipsychotic activities.

Such wasteful programs are still undertaken because we do not yet understand how drugs act at the molecular level. They reach receptors in the cells and there set in motion a biological response. Receptors are portions of very large and complex proteins or nucleic acids. I have compared this interaction to shadow boxing. One tries to hit a target without being able to see it clearly. If the details of receptors were understood, we could fit drug molecules to them. For the time being, trial and error have to give us the new drugs that are demanded by the medical profession. If trends in the relationship of chemical structure and biological activity develop in such programs, creative correlation can take over and more rational drug design can be planned. An example of my own work illustrates this procedure and shows how we were able to progress from relying on serendipity.

We had been interested in amines of the amphetamine and ephedrine type that have central nervous stimulatory capability. They sometimes have undesirable side effects and this prompted us to search for more specific alternatives. After preparing and testing many traditional analogs in a systematic manner, we decided to make a minimal change in the structure of amphetamine, that is by deleting only two atoms of hydrogen in its aminoisopropyl group. This led to 2-phenylcyclopropylamine. It was tested for amphetamine-like activities but gave unimpressive results. A few years later, attention was drawn to the rather poor inhibition of the enzyme monoamine oxidase (MAO) by amphetamine, and our cyclic analog was tested for that activity. It turned out to be 300 times more potent than the most effective MAO inhibitor encountered up to that time. Monoamine oxidase is an enzyme that destroys the biogenic amines, which elevate the mood, increase the sex drive, regulate blood pressure, and affect wakefulness and alertness. If MAO is inhibited, these biogenic amines survive metabolic destruction for a longer time and unfold their activity, including elevating the mood in endogenous depressions. Our compound was therefore developed as a clinical antidepressant and given the nonproprietary name of tranylcypromine.

There was no way of predicting whether tranylcypromine represented the optimum in low toxicity and high effectiveness among its potential congeners. Therefore a variety of structural analogs had to be synthesized and tested, a total of about seventy-five. Although some empiricism persisted in the task, the art of molecular modification had by then become more rational and more creative. One of the methods that offered itself to our work was based on the now generally accepted rules of bioisosterism. Its emergence illustrates well how medicinal scientists seek to unify their efforts in molecular modification.

A physical chemist, Irving Langmuir, compared very simple chemicals such as nitrogen and carbon monoxide and concluded that they resemble each other in many ways because their geometrical shape and electron clouds (later redefined as molecular orbitals) were closely similar. He called such compounds isosteric.

Later, Hans Erlenmeyer used Langmuir's discovery to compare biologically active chemicals with closely analogous structural sections (O, CH_2, NH etc.) that could be interpreted as having similar shapes and similar electronic arrangements. He observed that such predictable analogs usually shared certain biological properties as well. Erlenmeyer's analytical criteria for these comparisons were too restrictive, but this was remedied when Harris Friedman redefined them, made them more applicable to serial comparisons, and called the phenomenon bioisosterism. By that we now mean compounds whose molecules have similar shapes, similar electronic arrangements, and similar biological properties. Molecular changes of a prototype that will fit a particular description can be predicted reasonably on purely chemical grounds, and this concept has therefore cut down the number of analogs one has to prepare for biological screening. One could compare this to traveling to a far-off place with the aid of a road map instead of the older method of setting out in the general direction without a specific route.

Bioisosterism is essentially a summary of the chemical properties of compounds to be compared. The most fruitful comparable characteristic is the shape of the compounds because they have to fit into the proper molecular slot at the receptors. On the other hand, a molecule has to navigate to get to its receptors. It has to traverse membranes and other barriers, and it has to be soluble in aqueous body liquids and in the lipids of cells if it is to get to its site of action. For this purpose, a compound must have suitable physical properties. Several of them can be measured readily, for example its partition between blood and lipids.

This was proposed by Hans H. Meyer and E. Overton eighty-five years ago and standardized and refined by Corwin Hansch in 1964. By comparing both the chemical and physical properties of two or more compounds, the guesswork of their biological relationships can be narrowed further. Medicinal chemists have contributed to this approach to drug design by mapping groups of atoms that can be expected reasonably to take each other's place in organic molecules. The savings in time, effort, and expense cannot even be estimated. A great deal of intellectual inventiveness has replaced the traditional random trial of hundreds of chemical analogs.

Except for the crassest commercial competition, one does not want to make a drug that acts exactly like another one. One wants a drug with the same advantages and fewer side effects. That means the new drug must be different and must not have quite the same chemical and physical properties as the one that serves as a guide. Thus, in creating a new drug, one must recognize the limits within which one can still move without losing biological activity altogether.

The principle of bioisosterism has had vast practical applications. Many of the most useful antibacterial sulfanilamides were conceived this way, as were many of the semisynthetic penicillins and cephalosporins. Almost all the antihistaminics, both the traditional H-1 receptor antagonists and the newer antiulcer H-2 receptor antagonists owe their creation to this concept. In the case of the H-2 receptor antagonists, cimetidine and ranitidine, the final step in the design of their formulas depended on bioisosteric considerations. The antidepressant drug amitriptyline is a classic bioisostere of imipramine, which preceded it.

If an idea born in the mind of a theoretical physical chemist has had such tangible and beneficial results in medicine, should we not classify it as a creative act? I believe it was a manifestation of creativity, of abstract correlation of data, which in the hands of medicinal chemists blossomed forth into gratifying therapeutic realities. Intellectual innovation in a given science or scientific art must precede experimentation. Synthesis and a critical review of data and of their mutual interaction is as much a creative adventure as a breakthrough in the laboratory. The author who connects such loose ends contributes to the progress of a field as much as if he had performed a novel and illuminating experiment. Authors of books and reviews as well as experimental investigators who can understand the thinking and the jargon of two scientific areas are almost always the ones who originate stimulating new correlations and explanations. This is similar to the ability of a multilingual person who can insert the more precise words of one language into another and thereby enrich its meaning. The application of methodology well-known to one science but new to others introduces the most striking advances in each case.

All chemical subspecialties have been revolutionized by the invention of analytical and spectroscopic instruments over the last thirty-five years. Using ever smaller probes, these instruments have enabled chemists to determine the molecular weight, the chemical structure, the three-dimensional shape, and the distortions during chemical reactions of previously untouchable complex compounds. Whole new areas of macromolecular chemistry have been opened by these instruments, and new names such as molecular biology, chemical pharmacology, and so forth, had to be adopted for their subdivisions and university departments. Problems that took a chemist fifty years to solve, if they could be touched at all, can now be solved in three weeks or three months. Structures of contorted and convoluted complexity such as tetradotoxin, the vinca alkaloids, high-molecular proteins, enzymes, antibodies and the gene portions of nucleic acids now unveil their mysteries in record time. Tobacco smoke has revealed the presence of over 2,000 chemicals, and a vaccine for malaria is in the making because the proteins of the infectious plasmodial sporozoites have become understood. Over fifty chemicals have been identified as neurotransmitters and have opened the door to the treatment of a long list of neurological, psychiatric, and genetic diseases.

Explaining genetic processes in the molecular, detailed structural terms of the organic chemist has been particularly effective. It has become the basis for a mushrooming industry that makes use of recombinant DNA technology. The first practical results are in: the manufacture of human pancreatic insulin and the antiviral protein interferon by microbes, and others will follow shortly.

Through the application of these creative discoveries and correlations, we are on the threshold of understanding more and more fundamental life processes, including the creation and maintenance of memory, learning, and other acquired behavior. At the present rate of progress, within twenty-five years we will be able to discard superstitions and beliefs that have come down to us over the millennia. We are on the verge of explaining, in chemical terms, the acts of the creation of life, even of complex organisms. All this has happened and is happening because some inspired young men and women are applying new physical instruments and biochemical methodology to the study of life processes. They are using creative thinking and embracing problems of ever-increasing complexity, step by step, with defensible, experimental design.

Creativity in Science: A Personal Account

George S. Greenstein

Albert Einstein once wrote that the most incomprehensible thing about the universe is that it is comprehensible. When I was a student I did not know what he meant: the methods of science seemed reasonable to me, and their success assured. But as I matured and began doing research, I came to realize just how murky the business of science actually is.

Creativity is the tool we use to arrive at comprehension. A number of years ago I was lucky enough to stumble upon a discovery. In this essay I wish to trace, as best I can recall, the steps that lead to it. No discussion of scientific creativity would be complete, it seems to me, without a few such case histories in hand; they serve as laboratories in which various theories of human mental activity can be tested.

The following reminiscences might be termed psychological, but I do not like the term: our psyches are the only tool we have available with which to do science. Nevertheless the focus of my concern here is the mental process I employed, insofar as I am able to reconstruct it. Primarily, I offer my recollections to this conference in an effort to muddy the waters a bit; for as I survey the path I had followed, the utterly enigmatic nature of human creative thought impresses itself upon me—this and amazement that so messy, confused and fundamentally accidental an enterprise could ever have culminated in success. Einstein was right.

Pulsars are stars that have completed their normal evolutions and collapsed to radii of ten kilometers and densities approaching ten to the fifteenth (10^{15}) grams per cubic centimeter. In the collapse, their rotation rates increase dramatically and their magnetic fields are similarly amplified. Such rapidly rotating magnetized stars emit copious quantities of radiation; this emission is accompanied by a reaction torque acting to decelerate them. Pulsars, then, rotate rapidly and uniformly slow their rate of spin.

In the winter of 1969, however, one underwent a remarkable transformation. On the 24th of February the Vela Pulsar was observed and found to be in a normal state. By chance Vela was not observed again for a full week. When it was next monitored it was also found to be in a normal state, but it was rotating more rapidly. At some point within that seven-day period the Vela Pulsar had reversed its deceleration and sped up. Subsequently, the pulsar resumed its steady process of slowing down—but more rapidly than before.

At the time I was a postdoctoral fellow with A. G. W. Cameron at Yeshiva University. Cameron soon formulated a possible explanation for the speed-up, involving the sudden onset of turbulence within the pulsar. He postulated that the decelerating torque acted to slow only the outer layers of the star. If so, the interior layers would lag behind them in deceleration and so would rotate more rapidly. The pulsar would then no longer rotate as a unit, but would exhibit a good deal of shear in its interior.

Cameron knew that such shearing flows were prey to a variety of hydrodynamic instabilities. He focused on an instability discovered by Lord Rayleigh. This arises if, as one progresses from the center to the surface, the rotation rate Ω decreases more rapidly than one divided by the radius squared. In rigid rotation Ω was a constant, independent of the radius: the decelerating torque, though, would tend to reduce Ω in the outskirts while leaving it unaffected in the deep interior, thus forcing Ω ever closer to the critical pattern, which would be subject to the Rayleigh instability.

Once this pattern was set up, the flow would suddenly become turbulent, much as a pot of water heated to 212 degrees suddenly changes its state. This turbulence would stir the pulsar. In particular, the rapidly rotating interior regions would be carried upwards to mix into the more slowly rotating surface. Their high angular momentum would be imparted to it. The net result would be a sudden acceleration of the surface, in conformity with what had been observed.

It made sense. Cameron's explanation made no attempt, however, to address the second element of the event: the apparently permanent increase in the slowing-down rate subsequent to it. I recall our discussing this increase from time to time, but neither of us felt inclined to pay much attention to it. Pure laziness, I knew, but there it was: our discussions were lackadaisical and vague, and we would quickly move on to other things. Looking back on it, though, I do not really feel we were being lazy. It is incumbent upon everyone to separate the wheat from the chaff in order not to waste time on trivia; and although we never expressed our feelings in words—I can testify for myself that I never even clearly thought the matter out—both Cameron and I felt at the time that this element of the speed-up would turn out to be unimportant.

Several months later, however, rumors began circulating to the effect that the pulsar's slowing-down rate was still being monitored, and it was doing something strange. The Vela Pulsar's rate of deceleration apparently was slowly and smoothly growing smaller. Over the months the pulsar seemed to be gradually restoring itself to the very rate of slowing-down it had maintained before it had sped up in the first place.

Spurred on at last, I finally took the matter seriously. I asked myself whether anything in Cameron's analysis could be used to understand this feature of the event as well. But as I turned the question over in my mind, a strange tiredness would overcome me. I would grow unnaturally weary. At first I hardly recognized this strange reaction on my part, and I would briefly mull over the matter and then pass on to other things. But as the question kept returning to my mind so did the lassitude, and ultimately I recognized its cause. I realized that I had been avoiding the uncomfortable admission that I did not really understand Cameron's theory at all.

Whenever I have a difficult piece of thinking to do, I do it on foot. I set off for a nearby park; once there, the work began. Somewhere in Cameron's model was a feature that I did not understand. Try as I might, I could not put my finger on it. I could not even explain to myself the nature of my confusion. There was simply some point at which my mind stopped. Clarity of thought gave way to confusion, and I became muddle-headed and vague. Over and over again I would return to some point of certainty, some matter of which I could be sure and then take it forward, step by step, speaking to myself like a mother to her recalcitrant child. People were glancing at me. My mind kept wandering.

By noon I had gotten nowhere, and it was a relief to return to my desk. Cameron was in, and we ate in a local sandwich shop. During lunch, I put the question to him. Cameron immediately began talking. Like many scientists, he thinks out loud. As I recall, he seemed fairly satisfied with his explanation as it developed, but to me it seemed incomprehensible. I stopped listening. The sense of obscurity, of hopeless confusion, returned. I felt encumbered in fluff. It was difficult to breathe, and I experienced a desire to gasp. And then, inside my skull, something moved. There was a physical sensation of something turning, of a boulder that I had been trying to roll suddenly breaking free. I realized that I already knew the explanation.

Just before the sudden speed-up, the pulsar interior had been spinning more rapidly than on its surface. The surface was then subject to not one but two torques: a decelerating torque acting from the outside—but also an *accelerating* torque, transmitted by viscosity from the rapidly spinning interior. The slowing-down rate of the surface was determined by the competition between these opposing tendencies. Then the instability hit, mixing the star thoroughly. Afterwards the star was rotating uniformly; the interior was no longer rotating more rapidly than the surface, and so the accelerating torque had suddenly and completely vanished. The decelerating torque could now act unhindered, and the surface would naturally decelerate more rapidly than before.

Thus the increase in slowing-down rate after the event. But there was more—for as the months passed, the pulsar continued to slow. Of course it was only the surface that was slowing, and so the very same shear in the internal flow was gradually being reestablished. Therefore the same accelerating torque was slowly building up again upon the surface, and as a result its slowing-down rate was smoothly altering. Thus I saw that the rate of deceleration of the pulsar surface was a diagnostic, revealing much about the conditions in its deep interior.

Most exciting of all, however, was that now I had in my hands a means of predicting when the *next* of these strange events was due to occur. It would come when the state of rotation of the interior had been restored to the original pattern, subject to the Rayleigh instability—which is to say, when the rate of slowing-down had restored to exactly the value it had maintained just before the first speed-up. All we had to do was wait; and then, forewarned by my theory, we would have the opportunity of oberving the event in full detail.

All this did not come to me in stages. It came in a flash, instantaneously; and it came as a single unit, fully formed. The sensation was not like realizing something bit by bit, but rather of turning on lights. And as I have already mentioned, the feeling was not so much of discovering something as of realizing that I already had discovered it.

Sad to say, in the long run my idea fell by the wayside, for it was based on Cameron's theory, and time has shown that to be wrong. By now both his and my notions have become without significance. But no matter: the moment was one of those in which the practice of science crystallizes into a kind of perfection. All of us yearn for more of them.

Five years later I embarked on a project—unrelated to this subject—studying theoretically the long-term evolution of pulsars. As before, I was concerned with the effects of the decelerating torque acting upon the pulsar and the internal shear, or differential rotation, induced by it. But now my question was different. It concerned the rate of this differential rotation. I knew it would depend upon the frictional coupling between the interior and the surface, which in turn depended upon the stellar temperature: the hotter the pulsar, the stronger the friction and the weaker the differential rotation. So a pulsar, born hot and cooling with the passage of time, would undergo a gradual transformation in which the currents deep within its interior grew stronger. It was this readjustment, over geological ages, that I wished to study. I knew that it would have observable consequences.

The system was sufficiently complex that I was forced to simulate it on a computer. The program that I wrote to do so was, necessarily, equally complex. There were bugs. Such programmers' errors are anathema to scientists, but they are eminently suited to my present purposes: each is a small, self-contained problem to be solved, and the methods by which I surmounted them reveal something of the nature of the mental process.

On one occasion I spent more than a week tracking down such a bug. By the end I had nearly succeeded in memorizing the program, but I felt no closer to success than ever. Ultimately, of course, I did succeed, but by recourse to a method that to this day I cannot comprehend. One night I was awakened by a nightmare; and as I lay in bed, mouth dry and heart pounding, I realized that I already knew the source of the error. As in my previous example, the sensation was not of discovering an answer but of realizing that I had already done so. The difference is that in this instance, so far as I can tell, I had solved the problem while asleep.

On another occasion I located a program bug while standing in the shower. In this instance there was not the slightest sensation of effort: I had not even been aware of thinking at the time. It simply quietly crossed my mind that such-and-such a problem arose in such-and-such a manner. On a third occasion I thought of something while mowing the lawn and worrying about household finances.

My most severe bug did not surface for a full year. By that time I had improved the program to the point that at first it operated correctly, tracking the evolution of the pulsar as it slowed in rotation and cooled in temperature. But then, entirely without warning, the simulated pulsar would reverse this steady progress and heat drastically. At the same time its surface would commence rotating more rapidly. Its rotational behavior, in fact, reproduced very nicely the anomalous event that had been observed in Vela years earlier, but to the best of my recollection I paid no attention to this. Rather I regarded the result with irritation and commenced looking for my mistake.

This bug proved to be my most intractable hurdle. It resisted my most strenuous efforts. Ultimately, in desperation, I went so far as to cause the machine to print out every subsidiary step in its calculation. Seventy-five pages of printout, each densely packed with numbers, ended up on my desk; I poured over them endlessly. It was not for months that I realized there was no bug.

I have no idea when it was that I first saw this. I do know I did not realize it all at once. There was no blinding flash of inspiration. Rather, the more I pored over the printout, the more I understood that it made some kind of sense. As to what kind of sense it was, at first I could not say. At first I thought in terms of the program—the actual sequence of operations I had instructed the computer to perform. Then I began to think in terms of the mathematics—the equations the machine was solving. Only at the the end did I think in terms of the physics these equations modeled.

Had I been on my toes more than a year earlier I could have saved myself untold effort and recognized the origin of the Vela Pulsar's strange behavior. Contained in the numerical simulation of the pulsar's evolution was a point so obvious I had never bothered to consider its significance: that friction liberates heat. Thus without recognizing it I had been dealing with a feedback loop. In the loop the heat so produced led to more friction, which led to more heat, and so forth. It was a runaway, an instability—not a hydrodynamic instability, like Rayleigh's—but a thermal one. And the final step in the chain of explanation was that Vela's increased rate of rotation arose because its surface was more tightly coupled by the increased temperature to its more rapidly rotating interior. Thus the sudden burst of speed.

I would not claim that mine is the correct interpretaion of the Vela Pulsar's strange behavior: there is to this day no general agreement on this point. My interest here, though, is different: it is in probing the path that led to it, in hopes of pinpointing the essential elements of the creative process as it operates in science. First and most important question of all: is there a moral I can draw—a method I can isolate for *making still more discoveries?* I wish there was, but to this question I still believe I must reply "no." The story is full of too many twists and turns, stray circumstances, accidents. It is simply what happened.

A second point concerns my perception of those moments in which the activity of creative thought converged on a solution to a problem. In certain circumstances this occurred only after great effort; in others it seemed to come unbidden and by itself. But in every case I have had the same curious feeling that it was not *I* who thought of the idea, but rather that the idea, wholly formed by some outside agency, finally floated into my awareness. My personal experience has invariably been that the real activity of the mind lies outside of consciousness; that notions only become visible when they please. My mind is out of my control.

A third point is that nothing in my experience persuades me that scientific creativity differs in any essential respect from that exhibited in day-to-day thought. All people think creatively all the time. This opinion is bolstered by the fact that as a student of science I never took courses in creativity. No one ever taught me how to do it; conversely, I have not the slightest notion how to go about teaching it to my students.

At best I can give them the freedom to exercise this universal, essentially human talent.

For my final point I return to the Einstein comment with which I began. In this research I (perhaps) successfully reached an understanding of pulsars. But I did this without ever seeing one. Not once in the course of my efforts did I observe a pulsar through a telescope or perform an experiment in the laboratory. Nor was the computer essential in the long run—its only real function was to lead me to a conclusion I could have reached unassisted. How then did I operate? By thinking; that is to say, by introspection. *Theoretical research is the study of the contents of one's own mind.*

My thinking takes place in English, but no pulsar understands this language. I solved equations—pulsars do not. I went to school, learning the physics—the natural world never needed to. The natural world simply is.

The ingredients of research are the elementary rules of logic, language and mathematics, and these are strictly human things. They are inventions of our species. How can it be that their application tells us valid truths about the distant universe? Here is a brain: an electrochemical network. Here now is a pulsar: ten kilometers in radius, superdense. In some way the pattern of activity of the first can be made to mirror that of the second. The truly mysterious thing is not the pulsar; it is the method whereby we understand it, and this is indeed incomprehensible.

The Rationality of Creativity in Science

Mark L. Johnson and Nancy Tuana

Twentieth-century philosophical discussions of scientific creativity have been heavily influenced by logical empiricism, the central project of which was the "rational reconstruction of science," consisting of the clarification of the general logical form of scientific theories so as to exhibit the logical relations between observation statements and the laws and theories they confirmed or disconfirmed.[1] The goal of this project was the delineation of an infallible method of reasoning in science. This entire project relied heavily on contemporaneous developments in mathematics. Logical empiricists assumed that the fundamentals of arithmetic are derivable from pure logic and set theory. They then argued that scientific theories could and should be axiomatized in mathematical logic, which would thereby make evident their general logical form. Mathematical logic would then provide the method of reasoning, since formal logic and mathematics were free from researcher bias by being completely mechanical. Science was thus to offer objective knowledge of the world by commencing from an unquestionable starting point, observation, and moving via an infallible method of reasoning, logic and mathematics, to give us truth about the world.

The pure project of the rational reconstruction of science is now generally held to be defunct, yet in many important respects this discredited program still influences our view of scientific creativity.[2] Basically, logical empiricists held that creativity is not a proper object of philosophical reflection. The reason for this is fairly simple. As we have seen, the concern for infallibility resulted in the reduction of rationality to formal logic, seen as a set of mechanical rules. Reason, thus reduced, was nothing more than logical consequences derived from given statements according to such rules. But this definition of rationality left no room for discovery or creativity. For creativity, as everyone agreed, involves novelty, and it was thought that there could be no mechanical, rule-governed procedure for gaining novel insights. This view of creativity is well represented by Karl Popper, who places creative processes outside of the realm of the logical:

> My view of the matter, for what it is worth, is that there is no such thing as a logical method of having new ideas, or a logical reconstruction of this process. My view may be expressed by saying that every discovery contains "an irrational element" or "a creative intuition," in Bergson's sense. (Popper 1959, 32)

Thus appears what we shall call the dilemma of creativity. If a theory is to be successful in giving an explanation of creativity and discovery, then it must reduce creative thought to a procedure following a set of mechanical laws—to a deductive or inductive consequence of the explaining theory. But a process reducible to mechanical rules would not be creative. Hence, either the theory succeeds in explaining creativity, in which case creativity is eliminated, or the theory fails and creativity remains an enigma. Since logical empiricists were unable to formalize the creative process through logic, they adopted the latter alternative and relegated creativity and discovery to the realm of the mysterious—to the nonphilosophical.

One obvious way to question this image of discovery is to reject the view of rationality (as rule-governed logical form) upon which it rests. In his *Patterns of Discovery*, R. N. Hanson thus began the current debate that rages in the history and philosophy of science by urging a broader conception of rationality. An excellent reflection of the range of contemporary attitudes in this debate can be found in the collection of essays, *Scientific Discovery, Logic, and Rationality*, edited by Thomas Nickles. In alliance with those who urge the rationality of scientific discovery, we want to argue that the dilemma of creativity rests on two questionable assumptions: the reduction of reason to formal logic (rationality as nothing but logical or mathematical system) and the view that explanation is only deductive or inductive inference. By enriching the notions of rationality and explanation, as common sense and history of science urge, we offer an explanation of discovery that avoids the dilemma. Our "explanation" will not be a logical inference, but rather an account of at least some of the basic types of strategies involved in creative thought processes in science. We see such an explanation as story-telling, that is, a reenactment of the process of creativity designed to demonstrate that creativity is, in a broad sense, a rational process.

In order to show some of the ways in which creativity in science involves rational and patterned processes, we want to consider the work of the eminent endocrinologist Hans Selye, a central figure in the development of modern stress research.

As background to our analysis of this case study, we offer a brief definition and overview of Selye's notion of stress. Stress was first described by Selye as a biological syndrome:

> Experiments on rats show that if the organism is severely damaged by acute non-specific nocuous agents such as exposure to cold, surgical injury, production of spinal shock . . . a typical syndrome appears, the symptoms of which are independent of the nature of the damaging agent . . . and represent rather a response to damage as such.
>
> (Selye 1936, 32)

This syndrome is the manifestation of a state that Selye labeled "stress," which includes all the specific changes induced within the biological system of an organism. The agent of this state of stress is called the "stressor." Selye's main thesis is that stress is a general reaction that occurs in response to a variety of different stimuli. This biological reaction is characterized by a general increase in the production of certain hormones from the pituitary and adrenal glands that strengthen bodily defenses against different stressors.

Selye saw the stress reaction as an organism's adaptive syndrome in response to external stressors. He labeled the form of this syndrome as the General Adaptation Syndrome (GAS). The GAS consists of three phases. The first is called the alarm reaction, during which overall resistance to a stressor initially decreases, although bodily defenses such as inflammation are mobilized. In the second phase, the organism adapts to the presence of the stressor and maintains itself. Each organism has only a limited capacity to adapt, since doing so will deplete the organism. The third phase is the stage of exhaustion, which involves the breakdown or death of the organism. This view of stress as developed by Selye is, with a variety of refinements, still widely accepted.

Selye's first important discovery occurred during his first course in internal medicine at the University of Prague in 1925. In his dealings with patients in the early stages of various infectious diseases, Selye was impressed by a collection of symptoms ignored by his professor. As one patient after another was brought into the lecture room, they all seemed to Selye to share a large number of symptoms: coated tongues, aches and pains in the joints, intestinal distress, loss of appetite, and in many cases fever, enlarged spleen or liver, inflamed tonsils, and skin rash. Since these symptoms were common to many different diseases, they were of no interest to Selye's professor because they did not fit the accepted models of disease and bodily function and could not be used to establish a definite, specific diagnosis. But that there were so many symptoms common to so many diseases intrigued Selye, although he was not able to direct his attention to these matters.

Several years later, when he ran into trouble with his sex hormone research, Selye recalled his earlier classroom puzzlement with the cluster of nonspecific symptoms. Now a young researcher, Selye believed that he was on the track of a new sex hormone. When he injected rats with various ovarian and placental extracts to check for organ changes, he consistently found enlargment of the adrenal cortex, shrinking of the thymus, spleen, the lymph nodes, and all other lymphatic structures, plus stomach and intestinal ulcers. Selye's hypothesis was that this cluster of symptoms was caused by an as yet undiscovered ovarian hormone. But he found to his dismay that injections of pituitary, kidney, and spleen extracts also produced the same cluster of symptoms. Since these organs were not believed capable of producing sex hormones, it occurred to Selye that the symptoms might be due, not to any hormonal activity, but to the impurity of his extracts. In order to test this conjecture, he injected a (toxic) formalin solution into his laboratory animals. As he feared, the same cluster of symptoms was produced.

It was at this point that the dejected Selye began to glimpse a new way to structure these phenomena:

> As I repetitiously continued to go over my ill-fated experiments and their possible interpretation, it suddenly struck me that one could look at them from a different angle. If there was such a thing as a single nonspecific reaction of the body to damage of any kind, this might be worth study for its own sake. Indeed, working out the mechanism of this kind of stereotyped "syndrome of response to injury as such" might be much more important to medicine than the discovery of another sex hormone.
>
> As I repeated to myself, "a syndrome of response to injury as such," gradually, my early classroom impressions of the clinical "syndrome of just being sick" began to reappear dimly out of my subconsciousness, where they had been buried for over a decade. Could it be that this syndrome in man (the feeling of being ill, the diffuse pains in the joints and muscles, the intestinal disturbances with loss of appetite, the loss of weight) were in some manner clinical equivalents of the experimental syndrome, the triad (adrenocortical stimulation, thymicolymphatic atrophy, instestinal ulcers) that I had produced with such a variety of toxic substances in the rat? (Selye 1956, 25–26)

What Selye began to see what the possibility of a general *nonspecific* reaction pattern to any of a number of stressors.

Although Selye does not describe his discovery precisely in this way, what seems to be going on here is a change in the basic metaphorical structuring of his experience. He moves, we suggest, from one dominant metaphorical grasp of the situation, namely *Body as Machine* (and thus not homeostatic) to a novel understanding of *Body as Homeostatic Organism*. We speak of the Body as Machine metaphor here, because someone operating under the influence of this metaphor will understand, experience, and act toward one domain (that of bodily functioning) in terms of another domain of a different kind (that of mechanism). The use of metaphorical formulas is particularly helpful in showing the nature of the transformation Selye underwent when his sex hormone research began to falter. When Selye first began his research project, he operated under the influence of the *Body as Machine* metaphor acquired in medical school. Under that metaphor, there are, of course, several interlocking subsidiary metaphors such as those of isolated parts, functional assemblies, and repair and replacement of malfunctioning units. For example, the prevalent attitude at this time conceived the goals of surgery as the repair of injuries and the exturpation of diseased areas. Later in the twentieth century, when Cannon's theory of homeostasis became generally accepted (i.e., that various body mechanisms exist to preserve certain functional equilibria), there would be a corresponding change of attitude toward the goals of surgery, which was seen as a way to restore the body's functional balances (homeostasis) by surgical intervention. But this is to get ahead of the discussion. The point that we are trying to make here is that the *Body as Machine* metaphor was not isolated; it was a massive experiential structuring that dictated values, interests, goals, and practices.

Under the dominant *Body as Machine* metaphor, disease was typically understood as the breakdown of a specific part or as an invasion of the mechanism by a foreign substance or object. Thus, when Selye was in medical school and when he first started his research, any injury or disease was thought to be accompanied by a specific set of essential characteristics or symptoms. The idea that there might be a general *nonspecific* reaction to disease (or stress) did not have any place in the models, frameworks, and metaphors that defined medical science and practice at that time. Thus, Selye's professor had not been interested in the nonspecific symptoms shared by all the patients with infectious diseases. The recurrent grouping of symptoms simply wasn't (couldn't be) seen as significant.

The employment of the *Homeostasis* metaphor made it possible to understand the biological purpose of the cluster of symptoms previously discovered. Selye drew on Walter B. Cannon's (1932) notion of homeostasis: the maintenance of the ability to regulate and control steady, healthy states. At last, the nonspecific reactions made sense as the body's attempt to maintain a steady state in the face of stress. Our reenactment of the *logos* involved during this stage of Selye's discoveries is as follows: The first step was Selye's recognition that he was dealing with a syndrome of response, rather than a mere aggregate of symptoms. In searching for an explanation of the frustrating results of his sex hormone research, Selye began explorations that we see as depending upon the power of the *Homeostasis* metaphor. Under the conception of the *Body as Homeostatic Organism*, one would expect that every response would serve some function. Selye observed that the introduction of a toxin to laboratory animals caused this syndrome, and, moreover, the dosage of the toxin correlated with the strength of the reaction. Now a new explanation was possible under the *Homeostasis* metaphor—the syndrome was the body's general adaptative response to toxicity.

Here an even more significant entailment suggested itself. What if this syndrome was an adaptive response nót only to toxins but to any stressor (e.g., cold, injury, fatigue, fear)?

> If this were so, the general medical implications of the syndrome would be enormous! Some degree of nonspecific damage is undoubtedly superimposed upon the specific characteristics of any disease, upon the specific effects of any drug.
>
> (Selye 1956, 26)

Though there is no strict deduction at work in this creative process, there is a *logos*—a following-out of a pattern of entailments suggested by the change to a new dominant metaphor. The mechanistic metaphor was not dismissed completely, but it became background and was superceded by the new metaphor. The new structuring emerged gradually as various previously unrelated parts of Selye's experience began to take on a new unified organization. Some such dialectic between experience and metaphor is, we believe, responsible for the progress in Selye's research.

This tentative synthesis (organizing experience under the new metaphor) bore fruit. In particular, questions that seemed inappropriate under the old metaphor now seemed dictated by the new. That is, new questions occurred, new discriminations became possible, and new connections were suggested. Selye recognized that the new dominant metaphor meant

> that my first classroom impressions about the one-sidedness of medical thinking were quite justified and by no means sterile questions without practical answers. If the "damage syndrome" is superimposed upon the specific effects of all diseases and remedies, a systematic inquiry into the mechanism of this syndrome might

> well furnish us with a solid scientific basis for the treatment of damage as such. (Selye 1956, 26)

Given that the goal of the body was homeostasis, Selye was led to ask such questions as (1) To what extent is this syndrome really nonspecific? (2) What other manifestations are part of this syndrome? (3) How does it develop in time? (4) To what extent are the manifestations of the nonspecific syndrome influenced by the specific actions of the agents that elicit it? (5) What is the mechanism of this reaction?

The General Adaption Syndrome (mentioned earlier in this paper) played an important role in Selye's developing notions of disease. Early on, he recognized that the new metaphor called for a new understanding of the nature of disease:

> If this were so [If there were a general adapative response to stress], everything we had learned about the characteristic manifestations of disease, about the specific actions of drugs, would be in need of revision. All the actually observed biological effects of any agent must represent the sum of its specific actions and of this nonspecific response to damage that is superimposed upon it.
> (Selye 1956, 26)

Selye saw clearly that previous theories of disease could in no way account for the role of nonspecific response:

> What we have seen up to now, however, gives us no reason to believe that *nonspecific* stress plays any role in this [disease]. As far as we can see at this point, each damaging agent—every germ or poison—may be opposed by a special highly specific defense mechanism. (Selye 1956, 12)

In contrast to this, disease must be understood as "not just suffering, but a fight to maintain the homeostatic balance of our tissues, despite damage" (Selye 1956, 12).

This changing view of disease led to the dislocation of the notion of disease as lesion, and its subordination to an organic model of disease. Previously, the task of medicine was seen primarily as attacking and destroying the cause of the malady. This involved excision, patching, poisoning, bombarding with X-rays, and so forth, as counterattacks against the invader. Under the organic model, treatment also takes into account the organism's overall balance, both internal and external:

> *Stress therapy is not offensive;* it is not specifically directed against any one disease-producer (as are specific serums, antibiotics, and other chemotherapeutic agents). Stress therapy is not symptomatic, nor strictly *substitutional;* it does not act by merely eliminating any one specific symptom (as does aspirin in a headache), or by patching up a defect (as when a loss of skin is repaired with a graft, or a lack of vitamin with a curative amount of it).
>
> Stress therapy is instead *tactically defensive* in that it adjusts active defense (for instance, barricading off a disease-producer with inflammation) and passive submission (as permitting local death of limited cell-groups, or the spread of inoffensive diseaseproducers) in a manner favorable to the organism as a whole.
>
> (Selye 1956, 217)

For example, based on the lesion model, obesity has been treated surgically by removing portions of the stomach or the intestine so that only small amounts of food can be eaten or digested. Under the organic model, general environmental factors (exercise habits, self-image, personal relationships, work pressures, and so forth) are considered. This is not to say that the lesion model treatments are eliminated altogether, but rather that they must now be seen in relation to the wider, dominant organic mode.

A further important entailment of this organic model is the rejection of the dichotomy between sickness and health and its replacement by a degree notion of disease. According to the lesion metaphor, stress is a sign of disease. But under the organic metaphor, stress is only a sign of disease when it is so intense that the body cannot maintain its adaptive response.

> Textbooks usually define health as the absence of disease, and vice versa. The two conditions are alleged to be opposites of each other. Is this really so? Are they not rather different only in degree and in the position of vital phenomena within time-space?
>
> (Selye 1956, 221)

For example, a weight-loss typically indicates disease (as in cancer); however, the same phenomenon might be a normal response to the stress of an important vocational change. In the latter case, we do not say that a person is sick, yet he or she is not completely healthy either. Reference to the complete situation is essential to medical evaluation of the symptoms.

Still another result came from the developing exploration of the new metaphor—the view that every response of the body must have some function. Selye's work, and that of his colleagues, revealed more and more of the specific mechanisms by which the body identifies and responds to various threats. But also, they learned of the ways that the body turns off responses to threats when some other threats or injuries are more important. For example, when confronted by a major burn over a large portion of the body, the system will stop paying attention to a small infection in a finger and will throw all its resources into dealing with the burn. In other words, they learned more and more about the *anti*-inflammatory responses in the body and the purposes they serve for over-all well-being.

Once this much was understood, the researchers realized that when they believed a stress response to be unimportant to the long-range welfare of the animal, they could use anti-inflammatory reactions to relieve the animal's distress. For example, reactions to hay pollen (hay fever) could be turned off safely, because the pollen is not otherwise dangerous to the body. These types of subordinate results and their clinical applications in time helped to develop the large body of techniques for control of immune responses through "telling" the body *not* to carry out its usual efforts to preserve homeostasis.

All of the examples that we have explored so far have been cases of the following-out of entailments from the general organic metaphor. In each, the experimental questions posed and the discoveries they generated were made possible by the point of view provided under the new metaphor. It does not seem plausible to us, nor to Selye, that these questions would even have been formulated, let alone "answered," had the reasearchers been operating under the old model.

But the organic metaphor is itself subordinate to an even more far-reaching metaphorical schema: the *Body as Purposeful*. According to Selye, "It is evident that our whole unfiying concept is based upon teleologic thought: the principle of purposeful causality" (Selye 1956, 243). In all these cases, in which we have attempted to reenact the *logos* of Selye's discoveries, the notion of bodies as goal-directed (acting to achieve or maintain a dynamic, healthy situation) was vital to the framing of questions, the interpretation of results, and the building of a unified theory. As Selye says, "All my factual obervations were made possible by experiments planned on the assumption that stress responses are purposeful, homeostatic, reactions" (Selye 1956, 245). It thus seems fair to say that the entire creative research program would not have been possible without the change in, and working out of, the entailments of dominant experiential metaphors.

Since the rise of logical empiricism in the early part of this century, it has been a commonplace that there can be no "logic of discovery." As we explained at the outset, the reasoning behind this was simple—there is a logic only where there is a finite set of rules specifying the legitimate inferences and conceptual connections that govern chains of reasoning. But there is no set of rules for arriving at novel insights. Therefore, there can be no logic of discovery or creativity. New ideas may come from dreams, deep unconscious processes, or accidental occurrences, but such processes are not subject to rational reconstruction. No algorithm of creativity will ever be found—creativity must then be viewed as a non-rational process. We have suggested that this view has misled many philosophers into thinking that there is no point in even discussing creativity, since it lies outside the realm of the rational.

This, we believe, is a serious mistake; for, as we have attempted to show, creativity *is* a rational process. Our "argument" will not satisfy those who think that without an algorithm for creativity there is no logic. What we have found instead is a *logos* in this creative process—a patterned movement of thought. While there is no formula or set of rules for tracing out this line of thought, we hope to have shown that the movement is far from arbitrary or random, and it therefore has every right to be called rational.

Notes

[1] Virtually all of the central ideas of this paper were worked out in constant dialogue with our colleague, George McClure. We are indebted to him for his continual support and helpful criticism. We wish also to thank Eugenie Gatens-Robinson and Roger Robinson for their discussions of Selye's work and its role in current research in endocrinology.

[2] For an interesting discussion of the philosophy of logical empiricism and an overview of recent revisions of such tenets, see Harold Brown's *Perception, Theory, and Commitment: The New Philosophy of Science.* Chicago: Precedent Publications, 1977.

List of Works Cited

Cannon, Walter B. *The Wisdom of the Body.* New York: Norton, 1932.

Hanson, R. N. *Patterns of Discovery.* New York: Cambridge University Press, 1958

Nickles, Thomas ed. *Scientific Discovery, Logic, and Rationality: Boston Studies in the Philosophy of Science.* Vol. 56. The Hague: D. Reidel, 1980.

Popper, Karl. *The Logic of Scientific Discovery*. New York: Basic Books, 1959.

Selye, Hans. "A Syndrome Produced by Diverse Nocuous Agents." *Nature* 1936, 138: 32.

———. *The Stress of Life*. New York: McGraw Hill, 1956.

Exploration of the Mind and Its Relevance to Science and Humanities: A Personal Account

M. R. Raju

In spite of some philosophical background in my upbringing, I used to think that the humanities had no relevance to science or even day-to-day practical life. My experience during these past twenty-five years, however, has lead me to realize the importance of the humanities in the conduct of science. I have come to see that the human qualities underlying both the sciences and the humanities are not so very different. After reading books on creativity written from the viewpoints of different disciplines, for example, I began to perceive a common thread among those people who were creative, and during a two-day symposium held recently at Los Alamos National Laboratory, I found some of the ideas expressed by artists, psychologists, and scientists to be consistent with the ideas I had encountered in my own study of creativity. I want to emphasize that I have nothing original to add to this complex subject, except my appreciation of its importance. I will try to share my understanding in a simple and practical fashion.

Let me say first that I was born and raised in India where I received a graduate education in physics. Soon after completing the doctoral degree (in 1960), I decided to switch my field of study to radiation biophysics. Since that time, I have worked in the United States, starting at Massachusetts General Hospital and the Massachusetts Institute of Technology (two years), then to Lawrence Berkeley Laboratory for approximately eight years, and, finally, to Los Alamos National Laboratory, where I have been working since 1971. My research has been chiefly in the application of nuclear particles to the treatment of cancer.

In my research, physicists, radiation biologists, and radiation therapists interact with each other. Physicists as a whole are a confident bunch of people who feel thay can do anything. This intellectual security somehow becomes a part of their training and probably has something to do with the enormous developments that have taken place in physics during this century.

Biologists as a group, perhaps because of the complexity of their subject, are somewhat humble and in general easy to work with. If what

I say about biologists is true, then medical scientists should be even more humble, since we know so little in medicine compared to many fields of biology. However, somewhere in the training of medical doctors, they are taught to be confident to give their patients confidence in them. Although that may serve a useful purpose in the clinic, it is a hindrance in the interdisciplinary research laboratory.

These differences in training and in attitudes make interdisciplinary research rewarding, not only scientifically but also psychologically. It seems that we often get in each other's way. I have learned that, in addition to a sharp intellect, we must develop the self-awareness necessary to evoke the best in ourselves and in others.

The evolution and mutual influence of mind and body is a biological wonder. I only wish that our training made us more aware of the way body and mind interact, instead of being totally preoccupied with *only* our minds or *only* our bodies. I also wish that in our training we were exposed to the notion that there is much more to learn in life than what goes into good grades and advanced degrees. I am often appalled to observe the enormous waste of talent, energy, and time, even in institutions that lay claim to the best brains in the world.

World-renowned Indian philosopher and teacher Krishnamurti describes the noise generated in the brain in the following way: "One's brain is everlastingly chattering, chattering, chattering—whether scientific chatter, sorry, or ordinary daily life chatter." The physician and philosopher Lewis Thomas echoes these words: "It is hard to see how we could be in possession of an organ so complex and intricate and, as it occasionally reveals itself, so powerful, and be using it on such a scale, just for the production of a kind of background noise."

Now, the most important question is: What is it that comes in the way of getting the best out of us? Studying the biographies of some of the people who have made great contributions makes me wonder sometimes whether we all belong to the same species. However, I am convinced that with some effort and understanding, we can all produce some useful brain signals now and then, and at least reduce the background noise in our system of thinking and make significant contributions in our own small ways.

Fortunately, there is increasing knowledge and understanding of the functioning of the human brain; recent studies of electroencephalograms (EEGs) of the right and left hemispheres are helpful in elucidating their complementary and adversarial roles. The two hemispheres of the brain operate like two individuals, with each hemisphere capable of inhibiting the other. While the left hemisphere thinks in words, the right hemisphere thinks directly in sensory images. The left hemisphere generally tends to dominate the right because of the genetic advantage for interpreting verbal sounds. Also, the analytical mode, in which the observer separates himself from what he observes (a mode very useful for biological survival), is predominantly a left hemisphere function. While both of the hemispheres can listen and understand, the left hemisphere alone can speak, even though it cannot express very well in words what the right hemisphere really thinks. While the left hemisphere handles complexity linearly by sequence of small, logical steps, the right hemisphere looks at the entire situation at once, holistically. The many human accomplishments by the relatively few people who have achieved much may have been due to the unique ability to use these two hemispheres in a complementary, coordinated, more equal way.

Our normal state of consciousness is complex and could be predominantly a left-hemisphere function. Our consciousness appears to have been evolved for the primary purpose of ensuring individual biological survival that, although appropriate in the evolutionary development, is out of date in the present context of our more pressing concerns for collective survival. The brain and the nervous system receive an enormous amount of information from our senses and select information that is useful for biological survival. Because of this, most of the time we see but do not *recognize*, we hear but do not *listen*. This special process of selection can be called the "ego filter," in which information is consciously evaluated using the criteria "This is me" or "This is mine." Filtering information through one's ego radically alters the way we understand and treat that information.

In addition, information is affected by the normal state of consciousness in which the psychological struggle for individual survival gives rise to uninterrupted thoughts or constant chatter in the left hemisphere. The right hemisphere function is inhibited by such chatter. Hindu thought considers this chatter an illusion, even though for each of us it seems real. This mode of consciousness, with its chatter, is not conducive to creative work, to communication between the two hemispheres of the brain. As Nobel laureate Lord Adrian has said, "As soon as we let ourselves contemplate our own place in the picture, we seem to be stepping outside of the natural boundaries of natural science." Economist Schumacher puts in another way: "Nothing can be achieved as long as an egocentric 'I' stands in the way," and "in the process of doing good work the ego of the worker disappears."

The growth of science since World War II has further complicated the problem of doing creative science. The tremendous growth in knowledge promoted the development of a scientific bureaucracy that burdens creativity by adding more incessant chatter to our already noisy brains. Fortunately, in spite of this institutional noise, some people are able to produce brain signals strong enough to be heard above the combined noise levels that result from individual and institutional instincts for survival.

The strong survival instinct and its associated need for psychological security make it difficult to enter other potential modes of consciousness from our normal, ego-centered state of consciousness. Egotistical, never-ending thoughts relating to the "I" and "me" clog our minds. Although we are capable of noticing this stream of thoughts as it arises in our minds, we rarely pay the necessary attention to it. Such inattention permits these egotistical thoughts to direct our actions, which, in turn, produce more and more background noise. By paying *attention* to each ego-centered, self-serving thought—by capturing it as it arises at a split-second rate—the brain becomes silent. By being aware of this process, one can reduce the noise from the stream of thoughts.

According to a Chinese proverb, "You cannot stop the birds of sadness from flying over your head. But you can stop them from building their nests in your hair." Indeed, our thoughts seem like birds of sadness that have taken roost. Krishnamurti has analyzed the reason that we think the way we do: "Most of our thoughts come from self-protective instinct. Thought ceases only when the self is absent." While analyzing our thought processes and creativity, we should ask ourselves: Do thoughts control us, or do we control thoughts? Or perhaps most importantly: Should we control our thoughts? Charles Darwin answered this: "The highest possible stage in moral culture is when we recognize that we ought to control our thoughts."

The first step then in controlling our thoughts appears to be eliminating our egotistical, self-serving approach to thinking. The ego, or "the self," cannot be present when there is *attention*. In other words, in total attention there is no longer room or energy for the ego to intrude. Such attention can lead to other modes of consciousness. These altered states of consciousness appear to make fuller use of our nervous system. Rather, such states require of us the optimum use of both hemispheres of the brain and seem to prevent our getting stuck with the ego-centered left hemisphere alone. Shifting to the right hemisphere requires the loosening of the grip of the ego that filters the input from the senses. At the other extreme, schizophrenic patients tend to get stuck in right hemispheric thinking for extended periods of time.

Our normal, instinctual inability to switch to the right hemisphere mode and our intrinsic lack of an inner drive to make full use of our nervous system may be the reasons why some people use psychedelic drugs that overwhelm the left hemisphere mode and evoke the right hemisphere mode. Unlike those of most people, the perceptions of artists and other creative people are not limited to what is useful for survival and social functions. Instead, these people have the ability to loosen the grip of the ego when necessary. Unfortunately, our educational system is dominated by the verbal-analytical, left-hemispheric thinking; because of this, students find it difficult to foster and receive the faint signals from their right hemispheres.

Total preoccupation with our biological survival and psychological security (through ego) is a hindrance to creativity. The grip of the ego on all of us is very strong. As Suzuki has said, "We are too ego-centered. The ego shell in which we live is the hardest thing to outgrow." Continuously varied input, habitual processes, and fear help to reinforce and maintain the ego consciousness. Plato knew this: "Habit is no small matter."

According to Eastern philosophy, the ego is the root cause of our suffering. Long ago, to ease suffering, various techniques were developed to loosen the grip of the ego on our consciousness, These techniques include meditation, breathing exercises, singing, restriction of awareness to single objects such as a cross or a candle, focusing with full attention upon stimuli and our reactions in a detached way, and so forth. As Fritjof Capra has pointed out, the basic aim of meditation techniques is "to silence the thinking mind and shift the awareness from the rational to the intuitive mode of consciousness." I am not proposing that these techniques are necessary before one can become creative, but it appears that creative people develop an ability to enter altered states of consciousness when performing their creative work. Also, creative people are known to use intense visual imagery.

At the Los Alamos conference, which had as its topic "Creativity in Science," it was rather encouraging to hear from the speakers that every healthy human being is creative and that the basic reason for this creativity is life itself. Our speakers agreed that the creative potential in us is not realized mainly because of that powerful emotion, fear. Each in his or her own way said it takes courage to be creative. One speaker, Dr. David Perkins from Harvard, emphasized the need to work at the edge of one's competence. This, of course, requires the courage of a tight-rope walker. Another, Mr. Wilson Hurley, who is an artist, emphasized that the fear of being laughed at is a serious impediment to creativity. He gave an interesting example of this fear, referring to soldiers on a battlefield. He said that it is not love of country that makes a man give up his life on the battlefield, but rather fear of condemnation by his peers. Another speaker, Dr. Frank Barron from the University of California, recalled Samuel Johnson's definition of *walking*: "a series of arrested falls."

Everyone needs the courage to walk. Especially after falling, courage is *required*. As I mentioned earlier, fear is a powerful weapon that the ego uses to constrain our normal state of consciousness. All great works are produced when their creators are lost completely in their creative endeavor. As George Eliot put it, "In my best writings, there was 'not myself' which took possession of me, but my whole personality was acting merely as the instrument through which this spirit, as it were, was acting." In describing the creation of poetry, Goethe said, "The songs made me and not I them."

Finally, I would like to share with you a real story about Enrico Fermi. Dr. Anderson recalls that during the Trinity test at Alamagordo, Dr. Fermi was doing a small experiment of his own to measure the power of the first nuclear explosion while also helping Dr. Anderson gather samples of radioactive dirt. During the explosion, Dr. Fermi dropped small pieces of paper from a fixed height and watched them fall. By measuring the distance that the paper pieces were dragged by the blast, he calculated the power of the explosion. His calculation turned out to approximate closely the results from more elaborate experiments. His concentration was so great that while he was performing this experiment, he did not hear the sound of the explosion.

I should like to conclude my talk with a statement made by Wilson Hurley: "The greatest joy in life is to use yourself as you were built to work."

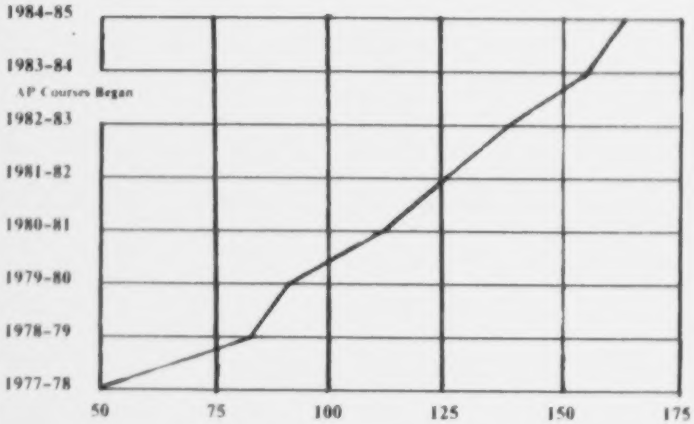
This paper represents work performed under the auspices of the U.S. Department of Energy at the Los Alamos National Laboratory, Los Alamos, New Mexico. The U.S. Government retains a non-exclusive royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U. S. Government purposes.

Creative Science Teaching

Claudia T. Melear

Enrollment in traditional science classes has increased at M. D. Collins High School in Fulton County, College Park, Georgia, since the inception of two non-traditional science classes six years ago. Interest in science at all levels has been heightened due to these two classes, and a two hundred percent increase (figure 1) in enrollment has been achieved in advanced-level science courses. Course offerings have doubled and now include physics, chemistry, human physiology, advanced-placement biology, advanced-placement chemistry, independent study in scientific research, and organic chemistry. The two courses that have produced these results are Science Teaching Insights and Independent Study in Scientific Research.

Figure 1: Average Number of Students in Advanced Level Science Courses*



*Physics, Chemistry, Human Physiology, Independent Study, Advanced Placement (AP) Biology, and AP Chemistry

Science Teaching Insights is an elective teacher-aide course for students who desire additional lab work in an informal setting. Students learn routine laboratory procedures and, in addition, choose a project of interest to them to complete during the quarter. Student projects have included erection of bird houses and feeders on school grounds, permanent display of birds in a natural setting in the classroom, and seashell mobiles—projects that enhance the school environment for all students and make science visible. Frequently, after taking this course, a student will elect to take additional traditional science courses. Additional sections of physics, chemistry, and human physiology have had to be added, and the advanced placement courses were instituted two years ago. Science has come to seem more approachable to the average student.

The target group for Science Teaching Insights is students who are interested in science for a possible career at many entry levels—gifted students as well as average and below average (twelve per quarter). The course is designed to give actual experience working in the lab. Students learn specific laboratory skills including making reagents for experiments, preparing agar plates for the microbiology classes, regular maintenance of the lab, typing, small animal care, microscope and dissection kit maintenance, and providing general assistance to other students. Students may select the course repeatedly as an elective, and some students have remained with me for five quarters. A student decides to become an aide by observing what the present aides are doing and then becoming approved by the science faculty and administration.

The students in this special course must elect one major project that they would like to work on during the quarter, in addition to their regular duties. This may be something of personal interest to them, or it may be something that enhances the school environment. Student projects in the past have included the following:

- Permanent preservation of laboratory animals
- Display of preserved birds in a natural habitat within the classroom
- Erection of bird feeders and houses on the school grounds
- Cataloging of shell, insect, and bird collections
- Making shell mobiles for classroom decorations
- Making terraria for classroom decoration
- Setting up and maintaining aquaria
- Maintaining bacterial collections

Students receiving credit for Science Teaching Insights are required to come early one day a week for continual lab-aide instruction. Former students report that they learned more from these sessions that they did from the regular classroom instruction. This course allows a student to get an accurate idea of what it's like to work in a lab—thus providing some career exploration in addition to knowledge. Three Independent Study students, for example, started out as student assistants, and hard work is recognized at the end of the year when Gold Test Tube awards are given to outstanding student aides.

The second course has already been mentioned. This is Independent Study in Scientific Research. This course offers academic credit and was born out of student interest in preparing projects for competition in science fairs and symposia. When I was assigned to teach honors biology, regular biology, and human physiology, I began to identify potential scientists, and after I had worked with them for a while, I found myself reluctant to release them. They in turn had become fascinated with science and wanted additional courses. In addition, I had found students who were interested in developing projects to enter into our state's many scientific competitions. At first, we worked on these projects after school; then we began using my planning period. Finally, our school decided to release me for a teaching period and to award academic credit to the students. This is how Independent Study in Scientific Research came into being.

Starting with one student seven years ago, the course now includes up to ten students per quarter. Our students have been among the NASA Space Shuttle regional finalists, two have been alternates to the Grand Award at the Georgia State Science and Engineering Fair, twelve have been invited speakers to the Georgia US Army Junior Science and Poets Humanities Symposium, and there have been many others. Naturally, these awards have generated much excitement at the school. Before the course was initiated, no student at our school had even entered a science competition. During the last seven years, almost every student in the class has won recognition, and many have won multiple awards at the state level.

Independent study students are also required to give an oral presentation of their work to other classes. This serves a dual purpose: it gives the students the opportunity to practice giving their work orally as preparation for the competitions they enter; and it gives the other students the opportunity to see if they might want to join the class, particularly after they learn of the commitment the course requires. Some Independent study students, for example, usually arrive a full hour before school starts, and they often remain later to work on projects. But they have access to their own "Biological Research Room" and this special treatment seems to confer an identification that they enjoy.

One of the ways that these students are encouraged to approach science creatively is through an imaging and inventing workshop during which they are introduced to a right-brain activity—visual imaging. This guided imagery experience extends into a creative inventing activity. Each participant is given a packet of materials and invents an object during a class period.

Visual imagery is a necessary part of the creative act (McKim 1980). Techniques such as relaxation, viewing and making mandalas to trick the brain into spatial thinking, guided imagery, and fantasy trips to musical accompaniment are used. The imagery experience precedes an actual inventing activity, using packets of materials prepared (and provided) from assorted household junk. Divided into groups of two, the students invent, name, and demonstrate a useful item, all to be done within forty-five minutes. "Scrounge" items for invention are donated by parents. Among the inventions that have come from this activity are the following:

- Arrow Shot Robot (ASR)
- Automatic instruments: house cleaner, nail driver, flag raiser
- Booty Pincher
- The Chef's Helper
- Chez Aves: Birdhouse and Feeder
- Combo-Portable Fishing Line and Bazooka Razor
- Hang-Around Child Entertainer
- Made-up Make-up Maker-upper
- Mexican Maraca Alarm and Superduper Incense Burner

The variety and ingenious nature of these inventions shows young minds engaged and experimenting.

Obviously, any program as extensive as this requires a good deal of support. In fact, we created a parent booster club, made up of the parents of all talented and gifted children in grades eight through twelve. The parents adopted a $1500 budget for each of the first three years of the program and then went out to seek it. This extra money has purchased additional science equipment and supplies, including Scholastic Aptitude Preparation materials. A telephone was installed for the program to help both teacher and students. But in addition to money, the parents act as volunteers who work regularly to type, duplicate, help in the lab, and solicit donations.

In return for all this support, the school has arranged for the booster club to hear speakers on topics of special interest during the monthly meetings. Speakers have included an expert on gifted children, a representative from the College Board who spoke on advanced placement, and most recently the Director of Financial Aid for the state of Georgia. This year, the parents are meeting by grade level and more parents are participating. Junior and senior parents have been coached, for example, on how to prepare their children for college; the parents of students in grades eight through ten have been told of the opportunities for community and volunteer work.

All of this effort attracted national attention when M. D. Collins High School was cited by the White House for excellence in science teaching and the director of the science program was selected State Award Winner for the Presidential Award for Excellence in Science Teaching. One reason why this program is unique is because of its support, and recognition must be given also to the local doctors, dentists, veterinarians, and businesses that have given continual financial support, materials, and time for student advising (Melear 1986, "Organizing Community Support").

List of Works Cited

McCormack, Alan J. 1981. *Inventors Workshop.* Pitman Learning. Belmont, C. A.

McKim, Robert H. 1980. *Experiences in Visual-Thinking.* Wadsworth, Inc. Belmont, C. A.

Melear, Claudia T. 1984. "Science Teaching Insights: A Laboratory Aide Training Program." *American Biology Teacher* 46 (2): 81-86.

———. "Organizing Community Support for Your Science Program." (*Georgia Science Teacher,* in press).

Zdenek, Marilee. 1983. *The Right Brain Experience.* McGraw Hill. New York.

Engineering and Humane Values: Engineers and Humanists Attempting to Solve Social Problems Together

George D. Curtis, Robert E. de Loach,
Patrick K. Takahashi, and Frank Watanabe

"Transparent Technology" may be defined as a technology or system that does its job so well that the user does not even know that it is there but can see or benefit from its effect nonetheless. The user knows what goes in and what comes out but does not know what goes on in between, or probably does not care to know what happened in the process. Thus, such technology often goes unnoticed (it's not "hi-tech!"), although there are significant social ramifications, as illustrated in the following examples.

The communications satellite has had a wider impact in the world than any other recent technical achievement. Every nation has or wants one, along with an airline and a seat in the United Nations assembly. If one thinks about the components that go into it—Clark's orbital theory, Von Braun's rockets, Stanton and Kilby's integrated circuits, Bell Lab's solar cell and receiver—it is the epitome of modern technology. Yet we dial the same telephone the same way we did twenty-five years ago. The signal may be going via wire, cable, and/or statellite. It makes no immediate difference; the medium is "transparent." We turn on the TV, just as we did twenty-five years ago and see a similar program. It may be coming to us via satellite, but we do not notice.

What, then, is the impact of this technology? One effect on a person is subtle. It may be that his long-distance phone bill starts going down and keeps going down until he takes advantage of the new rates by making more calls. Other effects are not so subtle. Today the telephone and related communication services (such as computer data) have pretty much replaced the letter in business and personal correspondence. Where it has not replaced mail, it has added to a tremendous volume of communications and added another virtual dimension to human interaction.

Or consider the xerographic process. The man who made it work retired about fifteen years ago (in Honolulu—perhaps he's in the audience) and since then competition and further innovation have reduced the price of a copy to a point where we *expect* to copy everything we write. Most of us don't know and have no reason to care how the xerox works, as long as what comes out of it looks like what went in. But think of the effect that this cheap and easy way to proliferate verbiage and images has had on teaching, publishing (the copyright law had to be revised), and the dissemination of knowledge. Perhaps we still write *some* letters instead of using the telephone so we can send copies to people. This technology—which provides us with more information than we can absorb and works like the photostat of fifty years ago—has had far-reaching effects on society because it is cheap and, to the user, non-technical.

A final example is the transistor radio. Here it mostly applies outside of North America and Europe where there have "always" been radios, and the spread of the transistorized device primarily resulted in the proliferation of similar-sounding rock stations. Distribution of $3 transistor radios around the world didn't just boost the economics of Taiwan and the politician who had the battery concession; rather, it gave leaders a method by which to influence, direct, and educate societies. Many of these people had probably listened to radios before, possibly in a village center or in their bosses' offices, but now they owned the radios and could get the word directly. The technology might be more appreciated if we had seen the first Texas Instruments lab model in 1956 that cost so much it first was sold by Neiman-Marcus. Yet it seems that all the *user* needed to know was how to change the battery and how to turn it on. He already knew about radio and it wasn't magic.

These technical advances made vast impacts, with more to come, on society and humanity, and there were all created by "someone else." Did the creators think about, could they even conceive of, these impacts? We know that the people who developed nuclear weapons visualized the effects and agonized over them. But what about the thousands of individuals working on the hundreds of components of the next computer, which has no preassigned tasks? Can we induce them to consider the effects of what they are creating? Can we also include in the education of technology *users* some notion of the role they play in shaping and controlling technology and its many impacts? If C. P. Snow is correct in saying that the two separate cultures are created by the intellectual segregation in our educational system, then perhaps it is time to bring the two cultures together. And what better way to do this than by having the two cultures work together solving the problems of the community in which we live. Can we, through education, instill a sense of the importance of interaction between the two cultures?

We tried at the University of Hawaii. Over a period of eight years, a continuing experiment in bridging the communication gap between engineering students and liberal arts majors at the university was conducted. This bridge was a course titled "Technology and Society." It was interdisciplinary and was taught by a team consisting of an engineering professor, a social science professor, and a community leader. The aim of the course was to create "the habit of interaction" between those who create and those who use technology.

The typical course had a composition of about forty percent engineering majors, with the rest ranging from art to zoology majors. The course originated in the College of Engineering, counted toward the general education core of all students, and was a special requirement of civil engineering majors. Class size ranged from forty to seventy students, and for most of its existence Professor Patrick K. Takahashi, currently director of the Hawaii Natural Energy Institute, was the lead instructor. He not only designed the basic structure, but he recruited additional instructors who would participate in a team effort with him.

Regardless of academic background, instructors shared the belief that there was a pressing need to instill in the students the idea that technology is a human-created institution that can be directed and controlled. The instructors also believed that multidisciplinary team work, if not more effective in problem solving was certainly valuable, and that the products were generally interesting and reflective of the normal processes of decision-making for social policy. It was felt that the sooner students became engaged in this process, the more meaningful their formal education would be. In some cases, their interaction in social problem-solving led to solutions that contributed to changing social policy.

Of course, there were additional goals, but these were changed from semester to semester, according to the unique personalities of members of the instructional team. In the end, the goals covered a wide spectrum of interests. A partial list of these goals includes the following:

- To broaden the base from which personal opinions are made, and to present complementary and conflicting views on the impact of technology on society and society on technology.

- To promote general understanding and appreciation of what the person in the other field is doing and pool multidisciplinary talents in accomplishing group projects.

- To improve the students' ability in restructuring and reorganizing given knowledge to formulate creatively new hypotheses and perceive higher order concepts, thus providing for thought-provoking discussion sessions and exams.

- To experience what is happening in society today through active participation in group-community interaction projects.

Although the course provided an overview of the entire field of technology-society interaction, one particular topic served as a theme each semester. Assigned topics included the environment, population, food, urbanization, health, and so on, but in the major class assignment, the interaction project that accounted for forty percent of the grade, interdisciplinary teams were encouraged to initiate their own personal crusade. Projects such as "Zero Automobile Growth," "Controllling Animal Population Growth," "Bringing Technology to Retarded Children," "Carbon Monoxide Poisoning: Walk Upwind of Busy Enclosed Streets," and the usual theme of curbing high-rise and highway proliferation predominated.

The general pattern of the class was to choose a topic such as alternate energy, then to have teams of five to eight research different aspects of the topic. Teams were deliberately mixed, assuring that about half would be engineering majors and half liberal arts majors. Teams then would recruit various experts in the community as well as at the university for interviews on their topics and to make class presentations. Beyond the list of names of known authorities and some basic guidelines on how to approach persons and make presentations, the students were left to their own devices in designing programs and handling the essential logistical details. The results of the their research, including records of their work procedures, were incorporated into a final paper. Some projects were more in the scholarly vein, such as a monograph on ways to achieve energy self-sufficiency for the State of Hawaii, while others were more process oriented, such as a program pairing immigrant intermediate students and native-born persons to foster understanding between the two and to assist in more rapid assimilation on the part of the immigrants. The range of projects was indeed varied since topics depended on student interest, who currently was teaching, and which issues were topical in the community at the time, as we have mentioned above. One outstanding product of an early class was the development and integration of its project reports into a comprehensive manual. This work was soon published (*Energy Self-Sufficiency for the State of Hawaii*) and used by students in succeeding classes and by others as a source book on energy.

In addition, students were generally required to review authoritative works dealing with technology's effects on social institutions and values.

This provided the students with a chance for individual work and creativity to balance the major focus on teamwork.

The instructors weren't always unanimously agreed on course content and instructional methods, and the efforts made to gain consensus on these matters could be the subject of another paper. It is brought up only to illustrate the *interaction* that went on between both the students and the instructors. The time devoted to arriving at agreement was not wasted, however. Much insight and perspective was gained into styles of problem-solving. In fact, the instructors may have gained more than the students.

As part of the evaluation process for this course, a survey letter was sent to former students some three years after the last class was taught. The Hawaii Council of Engineering Societies supplied alphabetized mailing lists of all members of engineering societies in the state. Available class rolls were checked against these lists and the phone book to locate graduates. A fair response was obtained and the response was bimodal. Many students thought the course was a waste of time, poorly organized, etc. (but often interesting), while others thought it was excellent, needed, and/or better than most courses. Almost no one was neutral.

A course with a title such as "Technology and Society" naturally promoted significant variation in topics and texts from course to course, depending on the instructors involved. The titles used included *Zen and the Art of Motorcycle Maintenance*, *The Existential Pleasures of Engineering*, *Problems of Industrial Society*, *Energy and Power*, and *Energy Self Suffiency for the State of Hawaii*.

The books chosen were unabashedly reflective of the instructors' bias. The bias?—technology is a human creation, not an abstract bogeyman. It is not the source of all pollution and materialistic values. It is more of a scapegoat for modern frustration than an evil monster. Rather, it is humans who are the source of these problems, and until this reality is accepted and people appreciate the power of the political process solutions will be few to nonexistent. People must become part of the process and learn the skills necessary to effect change if society is ever going to come to grips with the problems its passive submission to technology's power has created.

We found that this type of course can do a lot more than expand the consciousness of the class. The class itself, while in the process of becoming more aware, can extend its knowledge and talents into assisting the community. Everyone gains. The student tackles a real-world problem and interacts with decision-makers and future employers. The experience is much more meaningful.

The leaders of the community meet future leaders and, in turn, learn about the next generation. The university thus gains. In this time of adversarial relations among the bastions of higher education, the legislative branch of government, and the community, cooperation among all sections is a refreshing change.

Plenary Address

Language Theory and Darwinian Theory: Problems of Interchange and Autonomy

Gillian Beer

During the last hundred and fifty years, two major fields have drawn upon each other's evidences and—even more—upon each other's metaphors. From time to time, the desire for autonomy has involved repudiating and suppressing these links. In fact, for a theory to conceive itself as authentic and to establish itself as free-standing, it seems to need to obliterate traces of dependence. But such suppressed dependencies may reemerge later as a fresh field of enquiry. This pattern has significance for appraising claims of self-sufficiency in scientific language.

In *The Ecology of Language*, written in light of Chomskyean linguistics, Einar Haugen notes the evolutionist and ontogenic models that informed philological discussion in the later nineteenth century:

> It was common to speak of the "life of languages," *because the biological model came easily to a generation that had newly discovered evolution* [my italics]. Languages were born and died, like living organisms. They had their life-spans, they grew and changed like men and animals, they had their little ills which could be cured by appropriate remedies prescribed by good grammarians. New species evolved in the course of their "progress," often as a result of competition which assured the survival of the fittest. . . . Today the biological model is not popular among linguists. . . . Other metaphors have replaced the biological one, generally in response to the strong constructive aspect of our industrial civilization. (326)

Haugen here characterises a system of description that we might associate with Max Mũller's *Lectures on theScience of Language* (1861) or with George Whitney's *The Life and Growth of Language* (1875). Whitney's title emphasises an organic metaphor, though Ferdinand de Saussure admired him particularly for his emphasis on the arbitrariness of the sign. In his seminal *Course in General Linguistics* (1915), Saussure placed Whitney at the start of a methodological sequence that led to modern linguistics: he was followed by the German neogrammarians, thanks to whom "language is no longer looked upon as an organism that develops independently but as a product of the collective mind of linguistic groups" (introd. by Culler 5).

In *Language and Mind* (enlarged edition 1972) Noam Chomsky insists

> There is nothing useful to be said about behaviour or thought at the level of abstraction at which animal and human communication fall together. . . . This . . . is . . . often overlooked by those who approach human language as a natural, biological phenomenon; in particular, it seems rather pointless . . . to speculate about the evolution of human language from simpler systems—perhaps as absurd as it would be to speculate about the "evolution" of atoms from clouds of elementary particles. (70)

Chomsky emphasises discontinuity between other species and the specifically human power of language. Later workers in linguistics and historians of language-study emphasise the dependence of mid-nineteenth century linguistics on evolutionary and organic metaphors. An unacknowledged assumption of primacy for the more "scientific" field—the study of language depends upon the study of biology—may be implicated in that general view. However, it may be more revealing to reverse the emphasis. Much important nineteenth-century scientific work, particularly that of Lyell in geology and Darwin in evolutionary theory, drew upon new models of language development.

In an earlier essay ("Anxiety and Interchange: *Daniel Deronda* and the Implications of Darwin's Writing") I suggested that "cross-category of concepts" is "most active in areas of unresolved conflict or problem. It signals the significant anxieties of a period . . . the function of transposition may be as much to disguise as to lay bare." Further implications arise from that argument. One central debate in the past hundred and fifty years has been "man's place in nature"; language theory and evolutionary theory have been the two fields most preoccupied with this question. Two controversies in particular created connections between language theory and the biological sciences. One question was whether humankind uniquely possessed language and was thereby manifestly of a different order from all other living creatures. Descartes had earlied argued that language was what distinguished *Homo sapiens* from beasts, since even the stupid and insane could put words together so as to convey their thoughts, whereas the most perfect and thriving of animals could not do the same. This, he held, proved that animals had no reason, since so little reason was needed to enable man to talk (*Discourse on Method and Meditations*, 1637). Locke had seen that any enquiry into the origin of language would be an enquiry into "the very origin of the human race," and the point was taken up and quoted by Lord Monboddo in *Of the Origin and Progress of Language* (1773-1792). In that work, Monboddo shifts the barriers between man and beast, claiming the orang-outang, though silent, as a member of the family of man.

Monboddo's insistence that the orang-outang "belongs to our species" is based on an ordering of development that places the outang at the point just before the acquisition of speech, the point of "the invention of certain arts," particularly those of defence. After language, asserts Monboddo, comes government and laws. Monboddo adopted a developmental view of species, which he linked specifically to language acquisition. In his novel, *Melincourt* (1816), Thomas Love Peacock creates a marvelous parody of Monboddo's theory, both sympathetic and acute. He does so in the figure of Sir Oran Haut-ton—the impeccably silent, chivalrous (orang-outang) hero who is a thorough gentleman, skilled in the arts of defence and rescue, though not yet having acquired the skills of speech since he was brought to England from his native Borneo.

In August 1838, we find Darwin, who had been reading Monboddo and Horne Tooke, signalling to himself with cryptic boast the strength of the theory he was in the throes of realising: "Origin of man now proved.—Metaphysics must flourish.—He who understand baboon would do more toward metaphysics than Locke" (*Notebooks* 281). Max Müller responds to the implications of Darwin's theory as to an attack on the special status of humankind: "There is *one* barrier which no-one has yet ventured to touch—the barrier of language . . . no process of natural selection will ever distill significant words out of the notes of birds or the cries of beasts" (*The Science of Language* I, 357). (See my discussion in *Darwin's Plots*.) Darwin, who had ventured to touch that barrier privately in the 1830s, discussed it publicly ten years after Müller's book in *The Descent of Man* (1871), where he argues that both sexual selection and natural selection have developed the human power of speech. Alluding to Müller's claim that "the use of language implies the power of forming general concepts; and that as no animals are supposed to possess this power, an impassable barrier is formed between them and man," Darwin claims that, on the contrary, animals "have this power, at least in a rude and incipient degree" (135). He argues that human language is most probably the result of "the continued use of the mental and vocal organs leading to inherited changes in their structure and functions"—changes that have widened the gap between song, the calls of birds, the imitation of natural sounds, warning cries, and reasoned speech. In the notebooks, thirty years before, he had argued for "some necessary connexion between things and voice" (334), and in emphasising the musical beginnings of human speech, delightfully epitomised the relation between sexual selection and a fine voice. The first arts of music and the developed arts of language were in his view continuous: "A Melody on flute & epic poem, opposite ends of series of harmonious prose" (334).

The transformation of languages through time became a disciplined topic by the beginning of the nineteenth century. The second debate that informed language theory from the beginning of the nineteenth century was of equally great importance to Darwin, since it bore on methods of classification and on genealogical patterns of knowledge and descent. Hans Aarsleff, one of the most productive of recent historians of linguistics, asserts "It is universally agreed that the decisive turn in language study occurred when the philosophical, *a priori* method of the eighteenth century was abandoned in favour of the historical, *a posteriori* method of the nineteenth" (127). Towards the end of the eighteenth century there was a movement in the study of the history of language away from essentialist views towards the concept of language as a growing and developing medium. We can see this at the level of single words in the great interest in etymology (Whewell was at the centre of an active Etymological Society at Cambridge in the early 1830s while Darwin, his great admirer, was an undergraduate there). Another, and most important, level of debate was that of comparative grammar, which took its impetus from the work of William Jones and was established in the major studies of Franz Bopp. Both Bopp and Jones were Sanskrit scholars. Their work emphasised kinship and filiation between the languages and the Indo-European system, and emphasised too the idea of what Darwin was later, in another context, to call the "single progenitor"—a lost mother-tongue. In his review of Bopp's *Conjugationssystem*, Alexander Hamilton remarked that "Schlegel first indicated to his countrymen the sources of unexplored truths concealed in that distant region [India] and the important discoveries to which they might probably lead, in tracing the affiliations of nations, the progress of science, and the transactions of that mysterious period which precedes all history, [as] but that of one remarkable family." In *The Origin* Darwin turns to comparative grammar and to the different rates at which languages change to make clear what is novel in his ideas: evolutionary genealogy would explain the relations of diverse languages. And, as important, not all forms (linguistic or organic) need change greatly in an evolutionary system.

> It may be worthwhile to illustrate this view of classification, by taking the case of languages. If we possessed a perfect pedigree of mankind, a genealogical arrangement of the races of man would afford the best classification of the various languages now spoken throughout the world; and if all extinct languages, and all intermediate and slowly changing dialects, had to be included, such an arrangement would, I think, be the only possible one. Yet it might be that some very ancient language had altered little, and had given rise to few new languages, whilst others (owing to the spreading and subsequent isolation and states of civilisation of the several races, descended from a common race) had altered much, and had given rise to many new languages and dialects. The various degrees of difference in the languages from the same stock, would have to be expressed by groups subordinate to groups; but the proper or even only possible arrangement would still be genealogical; and this would be strictly natural, as it would connect together all languages, extinct and modern, by the closest affinities, and would give the filiation and origin of each tongue.
>
> In confirmation of this view, let us glance at the classification of varieties, which are believed or known to have descended from one species. (406)

Genetic terms (stock, varieties, filiations) move freely to and fro here across the descriptions of language and of descent.

Darwin uses linguistic theory not only as a metaphor or model but also as an *example* of evolutionary processes here. In the 1830s he had already been reading language-theory, as we know from his notebooks and his reading lists. The names of Locke, Dugald Steward, Monboddo, Horne Tooke, Brougham, and Hensleigh Wedgwood all appear. Henry, Lord Brougham's *Dissertations* excited Darwin because of Brougham's emphasis on the continuity between the powers of abstraction in animals and humankind: "says animals have abstraction because they understand signs.—very profound.—concludes that difference of intellect between animals and men only in kind. probably very important work" (Jan 21, 1839; *Notebooks* 342).

What Darwin did *not* understand in Brougham's work was his (extremely early) emphasis on the arbitrariness of the sign. We now connect this idea with the work of Saussure (who, as I have earlier indicated, drew on Whitney). But in Brougham we see how certain elements of language theory, which were to become of the first importance for twentieth-century work, were already available for discussion before 1840, though Darwin could not use them:

> Now connecting the two together [action and sign], whatever be the manner in which the sign is made, is Abstraction; but it is more, it is the very kind of Abstraction in which all language has its origin—the connecting the sign with the thing signified; for the sign is purely arbitrary in this case as much as in human language.
>
> (Brougham 195)

In Darwin's copy in the Cambridge University Library, he has drawn a line beside this paragraph and has written "Don't understand." What did Darwin not understand? What he needed and could use from Brougham was the emphasis on common origins and on animal intelligence. Animals understand signs; so do human beings: this demonstrates a common power of abstraction. Darwin's problems seem to concern the move from the idea of abstraction to that of language (and this indeed has continued to be a problem of theory and practice for workers with primates and language). His theory was at the time preoccupying him with continuity and connection: evidence of discontinuity and arbitrary relations might therefore, one might argue, not be within the current comprehension to his creativity. But something further is going on here. The recognition and suppression taking place concerns Brougham's insistence on semiotic arbitrariness as the prototype of abstraction. The relation between signifier and signified is, Brougham suggests, arbitrary in animal communication as in human language. This suggests a continuity of possible development and capacities between them. However, the arbitrariness of relationship between signifier and signified seems to be the point that Darwin baulks at. He believed in the musical basis of language, which could imply either a mimetic or an abstract relation of "things and voice." Darwin *needed* not yet to make up his mind concerning the question of the basis of language, and for this reason he believes himself not to have understood Brougham's argument. He may have felt reluctant to "cross the Rubicon" (as Müller held language to be between man and animals). But the reason for his delay in understanding has more to do with the problems of stabilising his views on the origin of language itself. Major theories must always *leave out* certain relevant questions. Creativity not only connects but *excludes* (in the interests of coherence and of uncertainty) resources apparently relevant to the current project. Those left-over resources may well later move back to the centre of a long-term debate.

Let us now look at two particular examples of the way in which Darwin's reading of language theory gave him terms to work with and problems to brood upon. Edward Manier has written concisely but revealingly about Darwin's views on language in *The Young Darwin* *and His Cultural Circle* (1978). Through my brief analysis here I hope to suggest the intimacy with which language theory and evolutionary theory were inter-implicated, metaphors and models moving freely back and forth, providing projects and hopes as well as difficulties.

The problem of essentialist versus developmentalist views of language is succinctly set out in Dugald Stewart's essay "On the Beautiful." He cites Diderot on the word *beau* in the *Encyclopedie* who, "after some severe strictures on the solutions proposed by his predecessors, is led, at last, to the following conclusions of his own, which he announces with all the pomp of discovery;—'That beauty consists in the perception of relations'." This, Stewart says, originated in an enduring prejudice "that when a word admits of a variety of significations, these significations must all be *species* of the same *genus*; and must consequently include some essential idea common to every individual to which the generic term can be applied." He counter-proposes that this "supposition [is] founded . . . on a total misconception of the nature of the circumstances, which, in the history of language, attach different meanings to the same words; and which often, by slow and insensible gradations, remove them to such a distance from their primitive or radical sense, that no ingenuity can trace the successive steps of their progress."

One notes in this passage the suggestion of *unconscious* processes of change ("slow and insensible gradations"), just as, later, Darwin in *The Origin* contrasts the consciousness of artifical selection against the improvement and modification which "surely but slowly follow from this unconscious process" of *natural* selection (148). We note too the transformation from the "primitive or radical sense"; the refusal of any static taxonomy, "some essential idea common to every individual to which the generic term can be applied": a refusal also of an essentialist view of species, what Darwin later called "the vain search for the undiscovered and undiscoverable essence of the term, *species*" (456). That refusal of essentialism is a necessary precondition of an evolutionist biology, but, strikingly, Dugald Stewart glosses over as being beyond dicovery, the phases by which words change, "no ingenuity can trace the successive steps of their progress." The genetic enquiry was *left over* to be undertaken later in other fields. Bopp and Grimm set out not only the *resemblances* but the *kinships* between languages. They showed that resemblance may in fact indicate separation. Their argument was based on the "natural transformations through inheritance of a single mother tongue, Indo-European. The original mother tongue (like the single progenitor of Darwin's theory) can be known only by reconstruction: most scholars did not believe that Sanskrit itself was the mother tongue; Darwin emphasised the irrecoverable form of "the one parent."

In a lecture of 1786, William Jones suggested that many languages would have to be considered as having "sprung from some common source, which, perhaps no longer exists." Bopp provided a programme of linguistic research that would analyse the grammatical structures of several languages, comparing their morphology and illustrating the common laws of change. "Many resemblances are evident at first sight, others are discovered by more careful investigation, and the more closely we analyse the recondite structure of the kindred tongues, the more we are surprised to find them constantly developed by the same principle . . . it will be well to avail ourselves [he writes later] of the first grammarians, and beginning with the simplest elements, contemplate the roots developing themselves under our own sight, as we may say, into various ramifications."

Again we can see at work here an organization of knowledge that will prove to be of immense worth for the development of later evolutionary and developmental theory, "roots developing themselves . . . into ramifications." The branching diagram of Darwinian theory shares its order with that of the comparative grammarians of the earlier nineteenth century. As Martin Rudwick has shown, Lyell found the metaphor from contemporary language theory of great worth in helping to organise his geological information and also in helping him to escape the blinkered empiricism of the geological society of his period (e.g., Lyell, *Scientific Journals*, Feb. 19, 1860, 352; Rudwick, "Transposed Concepts from the Human Sciences in the Early Work of Charles Lyell," in *Images of the Earth*, 67–83). The emphasis both upon the unreclaimable origins and upon the establishment of the regularity of the laws of change through phonetic laws was crucial as a thought-model of later workers in different fields. As Ducrot and Todorov make clear, the new emphasis in language theory on *inheritance* meant that the filial relationship between languages was expressed not only through resemblances: "The belief in natural change will lead . . . to a search for proofs of kinship within the differences themselves."

Etymology was the oldest form in which such linguistic change has been recorded, but it was possible to produce more than one convincing etymology for a single word, and difficult ever to establish an authoritative sequence of change, Although etymology was the first focus of work on language development, and remained a crucial concern (for example, for Darwin's cousin Hensleigh Wedgwood, who produced an etymological dictionary), it was the demonstration of phonetic laws that made possible the newest enquiries into filiation. Genetics, as Darwin was well aware, was not yet sufficiently advanced to be able to demonstrate the laws of transformation. It had not yet, that is to say, reached the degree of specificity that Bopp and Grimm had achieved in linguistic morphology. Language-study gave a hopeful model for future research.

Surveying the paucity of geological record, Darwin saw the scientist's activity as a "decipherment" of "characters." The history of the world is also a linguistic history, a palimpsest, riddled with gaps and lacunae—a record incomplete and fitful, "written in a changing dialect."

> For my part, following out Lyell's metaphor, I look at the natural geological record, as a history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page, only here and there a few lines. Each word of the slowly-changing language, in which the history is supposed to be written, being more or less different in the interrupted succession of chapters, may represent the apparently abruptly changed forms of life, entombed in our consecutive, but widely separated formulations.
> (316)

The real methodological problems produced by the degree of interpenetration of language and evolutionary theory become manifest in *The Descent of Man* where Darwin uses as independent sources of evidence what are in fact common terms, genetic and linguistic, which have been shifting to and fro between the two fields of study, a phenomenon I have discussed elsewhere (*vide* "Anxiety and Interchange"). Discussing the formation and origins of language, he cites first Lyell, then Müller, then by allusion his own earlier writing as it has been appropriated by Müller: "a language, like a species, when once extinct, never, as Sir C. Lyell remarks, reappears. The same language never has two birth-places. Distinct languages may be crossed or blended together. We see variability in every tongue, and new words are constantly cropping up. . . . The survival or preservation of certain favoured words in the struggle for existence is natural selection."

It was high time for the two fields to declare their independence of each other, to assert the autonomy of their studies and to obliterate for a while the lines of filiation. Evolutionary theory turned to genetics, linguistics to synchronic laws. Saussure remarks that the German neogrammarians "fought the terminology of the comparative school, and especially the illogical metaphors that it used. One no longer dared to say, 'Language does this or that' or 'life of language' since language is not an entity and exists only between speakers." But he wisely goes on to remark that to refuse metaphor entirely and "*to require that only words* *that correspond to facts of speech be used, is to pretend that these facts no longer perplex us*" [my italics] (5). Any suggestion that a field of study is authoritatively factual and autonomous, Saussure suggests, will be more misleading than accepting the provisionality of metaphor. This important insight recognizes that "left-over" metaphors may initiate further creative thinking.

Some of the metaphors that haunted the nineteenth-century debates have very recently become productive again, and the relations between linguistics and "man's place in nature" have entered creativity anew. In *Speaking of Apes: A Critical Anthology of Two-Way Communication with Man*, Jane Hill opens an essay on "Apes and Language" as follows:

> How shall anthropological linguistics assess the significance of recent experiments with apes and language? The question is a momentuous one. The answers may imply a paradigm shift, with Plato finally giving way to Darwin. (331)

Or, as Darwin had already exuberantly and secretly written in the 1830s, "Plato . . . says in Phaedo that our 'imaginary ideas' arise from the preexistence of the soul, are not derivable from experience.—read monkeys for preexistence" (324).

She continues: "Ten years ago, the answer from most established scholars to the question 'Do other animals have language?' would have been an unequivocable 'No.' Chomskyean rationalism dominated American linguistics and insisted on . . .'discontinuity theory'—the argument that humankind is not continuous in its abilities with other species."

Now, in the argument of writers such as Colin Beer in *The Origin and Evolution of Language and Speech* (1976) or Donald Griffin, *The Question of Animal Awareness: Evolutionary Continuity of Mental Experiences* (1976), the organic and evolutionary questions raised by nineteenth-century linguistics have moved back into a substantive status after a period as an obliterated metaphor. Erased filiations can be renewed and can give fresh impetus to further fields of enquiry.

Meanwhile, major works of literature sustain such hidden connections, even while the connections are for a time outside debate in scientific writing. We see this process in the episode in James Joyce's *Ulysses*, where language develops through several centuries to represent the embryonic growth and birth of a child, or, a profoundly complex example, T. S. Eliot's *The Waste Land*, with its fierce refusal of any "progressive," evolutionist view of language or civilization, its final return to the Sanskrit sources of language and wisdom: *Da, Dayadvham, Damyatta*, which alone provide some coherence to the fragments he has "shored against his ruin."

List of Works Cited

Aarsleff, Hans. *The Study of Language in England, 1780–1860*. Princeton: Princeton University Press, 1967.

Beer, Gillian. "Anxiety and Interchange: *Daniel Deronda* and the Implications of Darwin's Writing." *Journal of the History of Behavioural Sciences* 19 (1983): 31–44.

———. *Darwin's Plots*. London: Routledge, 1983.

Brougham, Henry Lord. *Dissertations on Subjects of Science Connected with Natural Theology*. 2 vols. London, 1839.

Chomsky, Noam. *Language and Mind*. Enlarged ed. New York, 1972.

Darwin, Charles. "The Notebooks on Man, Mind and Materialism." In *Darwin on Man*. Ed. Howard Gruber and Paul Barrett. London: Wildwood House, 1974.

———. *The Origin of the Species*. Ed. J. W. Burrow. Harmondsworth: Penguin Books, 1968.

Hamilton, Alexander. Rev. of Bopp's *Conjugationssystem. Edinburgh Review* 33 (1820): 431–435.

Haugen, Einar. *The Ecology of Language*. Stanford: Stanford University Press, 1972.

Müller, Max. *Lectures on the Science of Language*. First Series. London, 1861.

Saussure, Ferdinand de. *Course in General Linguistics*. Ed. J. Culler. London: Collins,1974.

Sebeok, J. T., ed. *Speaking of Apes*. New York and London: Plenum Press, 1980.

Wilson, L. G. ed. *Sir Charles Lyell's Scientific Journals on the Species Question*. New Haven and London: Yale University Press, 1970.

Keynote Address

Why Machines Cannot Do Science

Lenn E. Goodman

We may picture the activity of scientists in technological vignettes—stainless steel centrifuges, glass pipettes, computer signals, Van de Graaf generators, the silence of deep space, and the seeming impersonality of pure mathematics. But conceptually, the work of scientists has more in common with that of poets, composers, novelists, and painters than with that of machines. For scientists are concerned with discovery and invention, eliciting pattern and comprehensibility from the seeming disorder of disparate phenomena—data, numbers, discrete perceptions—bringing insight to observation.

Because creative thinking takes us beyond the given and expected, creativity itself tends to evade analysis. Mechanistic theories generally attempt to assign creativity to chance. Romantic theories make a mystery of creativity, substituting awe for understanding. Both approaches have been applied to science, sometimes in combination. It is easy to believe that scientists merely describe what they sense, tote up instances, randomly reach a plausible generalization, trivially devise a crucial test, and then pronounce: confirmed or disconfirmed. This mechanical model overlooks the question of the relevance of observations. It slights the most creative phase of scientific work—relegating to chance or the unknown the framing of hypotheses and design of experiments. But chance is inadequate to perform any intellectual function. And to appeal to the unknown is to admit defeat in the endeavor to understand scientific creativity.

It is natural to want to know how discoveries are made. So much depends on the creative process, and it is so challenging an object of curiosity that we hope to take it apart bit by bit, put it back together, reproduce it—perhaps mass produce it—and train ourselves and others at it. But the process and course of scientific discovery, like that of art and poetry, and unlike any merely mechanical performance or routine, cannot be modeled by an algorithm or derived from a formula. It can be evaluated only as it emerges. Yet it can be understood, appreciated, found excellent, or capable of improvement. I shall argue that scientific creativity cannot simply be replicated or inculcated yet can be taught, and that creativity cannot be produced by chance or necessity but rather is the proof of the joint insufficiency of these two categories as modes of

© Lenn E. Goodman 1985

explanation. Creativity can be accomplished only by thought, and I shall try to describe the anatomy of creative thought as I understand it, to explain why creativity cannot be modeled and yet can be regarded as a human achievement.

Mythic thought characteristically assigns creative acts to superhuman intervention. The inventive powers that originate agriculture, industry, language, sometimes the great epics, and surely the laws and institutions of a society are ascribed to culture heroes of superhuman proportion. Culturally important features of nature—the sun's tarrying to warm the fields, or the forming of rivers and lakes—join these works, as in the myths of Maui or Hiawatha. Today myths of dehumanized creativity continue in stories of earth visits by intergalactic voyagers of superior intelligence and power. They persist as well in the tendency to assign mysterious, superhuman powers to machines.

Culture hero myths are intellectually potent; much of their pleasure arises from their intellectual scope. But the stories have relatively little to say about the nature of creativity. Like other myths, they operate most actively not in answering the questions they profess to ask—about where the mountains came from or who first planted corn or raised the islands from the sea—but in what they take as premises. They identify, differentiate, and appreciate the features of nature and culture. They situate us in a social as well as natural environment. Creativity, the seeming common theme, is either taken for granted or attributed to the gods or fates, or to the prowess of the culture hero, who is thereby assimilated to the gods or fate. The charismatic leader and lawgiver, the mad lover of romance, and the poet or pianist of Romantic theory are alike in this regard: their charisma is divine. Their feats prove either their divinity or their being touched by the divine.

Theologically, it is problematic to assign divinity to a finite and fallible being. So culture heroes tend to lose either their divinity—by satire or perhaps by death, natural or ritual—or their humanity, by apotheosis, acquiring the remoteness of gods. Those romantic figures said to be touched by the divine incur no theological objection. But the metaphor of *touching* papers over ignorance: nothing has been said about creativity itself. When we ascribe life on earth to life elsewhere, as Fred Hoyle has done in recent years, we only push back the question. When we defer to an occult property or black box called creativity, we have described nothing. If we impute responsibility for that box to the divine, whether deemed transcendent or rendered compact with the romantically envisioned "genius," we may have said a little as to what qualities we think of as divine but still have said nothing about what creativity might be or how it comes about. Indeed, we have obstructed access to such questions by appealing to ultimate causes before proximate ones have been examined, by naming the effect as though it were a cause.

Mechanistic theories might seem to do the opposite. Their linguistic style is analytic, abstract, and pure—far beyond appeals to magic. But because creativity tends to elude mechanism, mechanistic theories of creativity take refuge in the great myth of mechanism: chance. Chance in a mechanistic framework is as slippery a notion as charisma is in a romantic one—for it too papers over deep structural fissures in the framework itself.

There are two readily confused conceptions of chance: Epicurus' (tychistic) conception of uncaused or spontaneous events, and Democritus' notion (refined by Aristotle) of fully determined but unanticipated events, dependent on normally unrelated causes. Tychistic chance survives in the idea of quantum indeterminacy and has been appealed to in the twentieth century, as the clinamen was appealed to by Epicurean philosophers, to provide a mechanical foundation for free will, and (in tandem with determinate modes of interaction at the atomic level) a foundation for the cosmic order. Randomness is at the basis of modern genetic and evolutionary theory, the kinetic theory of gases, and indeed most of modern mechanics—to the point that determinacy can be interpreted as a product of randomness and vice versa.

The idea that human creativity derives in some sense from chance or random events is at least as old as the work of Democritus and Epicurus; its critique is as old as that of their rival systems. First the myth: discovery rests on accident, serendipity, as in Charles Lamb's retelling of the Democritean myth as a prehistoric tale of the discovery of cooking. Epicurus had the advantage of criticizing the Democritean model: it held, puzzlingly, that random collisions of particles could generate the richness of our world. Despite the problems inherent in any reductionistic account, the theory survives in Monod's conception of nature: we ourselves are products of random collisions, and our discoveries are just another kind of collocation, juxtaposing our interests with what seems favorable to them.

Of course, the notion that evolution depends on blind, uncaring chance embodies a tendentious rhetoric. Putting the shoe on the other foot: the same random mutations that produce genetic disabilities are responsible as well for evolution. But the notion of serendipity, like that of genetic opportunism, is rather weak in accounting for how it comes about that beings should have interests at all. The pursuit of stability and complexity is taken as a given, projected as a universal appetite for being. If this appetite exists, it is not passively mechanical. Mechanistic theories simply presume that intelligent beings are capable of perceiving their own interests. The external and existential contributions to the constituting of interests are ignored.

Epicurus argued that passive and inert Democritean atoms are inadequate to account for aggregation. Even at the atomic level spontaneity is needed, or a world containing colorful and living beings would never have evolved. Human creativity intentionally combines elements, syllables, words, or ideas, mirroring the constructive creativity of nature. Democritus had made the smallest parts too simple. If a spontaneous, perhaps inexplicable, movement had not been present from the outset, even in the atom, nature would have remained forever a lifeless rain of atoms. If the axiom of mechanism was to be *ex nihilo nihil fit,* then Democritus had assumed too little; the mechanical properties he allotted to the atoms might account for their ricochets (once they are set on a collision course), but there will be no joining without spontaneity. Some interpreters of Epicurus find in his criticism of Democritus a demand for will and life within the atoms, abandoning mechanism altogether for a form of vitalism. Most varieties of mechanism, however, find life and will neither within the atoms nor beyond them (since they deny primary reality to anything but atoms). They either deny the reality of life and will—and thought—or ascribe their manifestations to the complexity of atomic and molecular organization, seeking by this means to avoid the sentence of their own dictum that nothing comes from nothing.

Creativity, then, on the Democritean model, is reduced to accident; on the Epicurean model, it is packed into the elements themselves (at least in embryo) and then allowed to emerge progressively, to be recognized in appropriate forms at each successive level of evolution. Now the Democritean model is problematic for the same reason that the magical is so—indeed, it is another version of the romantic myth, substituting chance for the divine without diminishing the sense of mystery. As often happens with myths, the moral might be altered but the story is not changed much, and the obscurantism not at all: some mortal chanced upon an opportunity for profit. We are not told of the inquiries and explorations that would make a situation apprehensible as an opportunity. Yet apprehension of an answer requires at least the tacit posing of a question, and the mechanism of Democritus or Monod is powerless to explain (without circularity) how or why such questions are devised. To make serendipity the universal model of discovery is simply an artificial way of excluding the purposive and discursive character of the intellectual process. The paradigm of invention as accident is not a finding but a postulate of mechanism, and if creative discoveries take place by means other than those allowed for in the mechanistic myth, mechanism is to that degree, discredited.

The same can be said of tychistic models. If they depart from Democritean reductions of creativity to random collisions and still do not simply presuppose what they are seeking, Epicurean theories attempt to derive creativity from a spontaneity that is conceived as a mechanistic countercase to strict mechanistic determinism. Apart from questions as to the nexus between spontaneity—say at the quantum level—and the process of thought, the classic difficulty remains that blind events, containing no element of consciousness or control, are made the ultimate determinants of the course of thought. To the extent that creativity involves the primary action and control of consciousness as an independent rather than dependent variable, the tychistic model is refuted. Thus, if creativity is originative and consciously controlled, both forms of mechanism are powerless to account for it.

What then is creativity? and what is scientific creativity in particular? I would define as creative any process that adds to the given. Paradigms of creativity are the divine creative act, the human fashioning of an artifact, procreation in animals and plants, and the evolution of living species, chemicals, or stars. Values are involved from the outset: something is better than nothing; and, among the things that are, there are objectively better states for things to be in, defined in part by what a thing has been, in part by the open (but not wholly unstructured) possibilities of what it might be. The involvement of our interests makes it notoriously difficult to define just where, in any given state, the best direction of development may lie. Indeed, this difficulty parallels the difficulty of defining creativity in concrete terms. For creativity itself may be understood as the success that beings are capable of achieving in defining the undefined future for themselves. Notions of order, complexity, stability, and fecundity may help orient us to creative directions. But each such notion is partial. For finite creatures, creative striving is necessarily fragmented and aspectual, reflecting the diversity of their powers. The completeness of the notion is captured (but not contained) only in an open-ended concept like that of perfection.

In the realm of judgment, creativity is represented by the synthetic. I hasten to add that even "analytic" judgments are synthetic in their own way when they detect or pinion an implicit or unrecognized relation. The abstractions and analyses of scientific laws are synthetic in the relations they propose. Even in abstracting from concomitances deemed casual, they are synthetic, incorporating criteria of relevance and irrelevance that the data do not present. Synthetic judgments are creative insofar as they add to the notion of the given. Where does the addition come from? Logic seems to tell us that no stronger claim can be arrived at from a weaker—no outcome unless implicit from the outset. But creativity, if it is real, is not deduction. It departs from the givens and does not merely unpack them. How can this happen? To assign all to external sources, human or superhuman, is to falsify the experience, just as to make the I the sole and self-creator is to negate the role of tradition and of God. To explain away synthesis as mere rearranging of elements ignores new contributions of form, energy, and information. For something is always added by rearrangement, as the fable of Maxwell's demon makes abundantly clear. And, to be sure, there is more to synthesis than rearrangement. Something is added materially as well. Synthesis appropriates, adapts, and even generates materials. The definitions of the initially given elements of any synthesis, for this reason, are as insufficient to define its product as is arithmetic to convey the notions of geometry.

We create an illusion of analyticity—of sentences following simply from their premises—when we erect elaborate, mechanical systems that allow us to derive conclusions without much thought. But in so doing, we tend to overlook the systems of convention that make possible the construction of the framework. The pragmatic nexus of assumptions is always far richer than the conclusions it allows to be entailed. Without far more in the way of conventions and exclusions than ever could be stated formally, no practical step of reasoning can be made. Many of the assumptions necessary to any process of thought are implicit, external to the formal, abstract system in which thought is recapitulated or canonized. These are supplied to the artificial structure as conventions of operation. The process of inference remains synthetic. The same is true, of course, with machines. Their automatic features diminish but can never eliminate the role of thought—both in their design and in their use. The very hardness of their surfaces and discreteness of their circuits involve elaborate systems of tacit premises that exclude manifold (probably infinite) possibilities. Whatever expression of thought emerges from the operation of a humanly devised machine is the product of human processes of thought incorporated in the building and operation of the machine.

The illusion of mechanism in nature—seeing all events as merely passive changes—fosters a corresponding illusion about thought. Mechanism "commonsensically" supposes matter inert, conserved, and simple in its properties. But matter is active, dynamic, and complex; even at its most "elementary," it is capable of harboring energy—of transformation into energy. On a naive mechanical model, we think of change and therefore thought as passive play among blocks or beads and imagine that nothing can come out of such a collection that did not go in. But the assumption neglects both the parsimony and the resourcefulness of nature (including human nature), nature's generosity, and its art. Active elements can enhance their capabilities for action and self-direction. All changing, moving systems are given energy and body as well as static space. Organized, organic systems can take resources they are not given, appropriating energy, assimilating matter, elaborating and designing structure, acquiring and enlarging information—if necessary inventing it.

To assume that nothing can be known, accomplished, or acquired beyond the given is to assume no difference between the printed works of Shakespeare and the rows of brass matrices for type that lie in print shop drawers. To assume that thought is an electric pattern in the brain of a man or a machine, expressing rather than directing a rearrangement of molecules or their subatomic parts, is to ignore the role of the subject and the fact of reflexivity, which is the basis of all higher order organization. It is to ignore the role of authors and assume that things like matrices for type have power not only to arrange themselves but also to fill themselves with molten lead, direct its casting and cooling, spread ink upon the resulting type, press that inked type upon a page, dry and bind, sell and distribute—all tasks requiring skill, foresight, and intent, and all going beyond the role assigned to matter in mechanistic accounts of thought.

I have been arguing that all thought is creative by its nature. The same point is made in Kantian philosophy and Gestalt psychology. What we call creative thinking in particular is that which goes particularly beyond the given in a direction recognizable as fruitful—that is creative of real value, adding to reality intellectually, practically, and aesthetically. Conscious creativity is admired not just because it is fruitful, but because it does not wait for afterthought to recognize and choose, sometimes to create its new direction. But the newness of a direction is a sign of boldness, perhaps of insight, not necessarily of fruitfulness, which is the test of creativity. An art museum presents as a paradigm of creativity graphic patterns generated by a computer governed by the sound of confined moths' wings beating against a microphone. Here the mystique of chance is merged with that of genius—identified by the trappings of the bizarre, the vagaries of simulated madness. Confusing novelty with creativity is just one way of taking the part for the whole, the wrapper for the candy. Mechanism unaided presents a subtler error of the same kind.

Recently, I read that bits of Albert Einstein's brain tissue have been examined. The cells seem to be far more elaborately linked than those in typical samples. To pretend that we have found here an explanation of Albert Einstein's insightful way of thinking about physics is on a par with the fantasy that a future archeologist could reconstruct the interactions of the people of New York by examining the linkages of one of the great telephone exchanges of that city while never seeing the exchange in action or hearing voices on the line. We begin to understand science when we begin to recognize that just as no typewriters (with or without monkeys) could ever write the Book of Psalms, so no machine or combination of machines can conduct a scientific enquiry. We cannot just open the windows of observatories on Mauna Kea, hook up telescopes to photo cells, and send the scientists home. Machines are not curious; they are never struck with wonder or with awe. And machines are not discerning. If a machine did print out the Book of Psalms, whether at random, from arbitrary instructions, or as a mere change of phase, say from disk to paper, the output would drop in the bin—along with pages of the phone book, correspondence about this conference, or the static that randomizing instructions would be most likely to produce. There are no psalms without a reader and no significance for markings on paper or disk without a contextual framework within which meanings can be located or assigned. Without criteria of selection, there is no differentiation of noise from signal, and machines—operators whose output is governed by their input—are powerless to generate criteria of selection for themselves.

If we compare creative activity in mathematics, in the arts, and in the sciences, we find that all three construct fictions, symbolic or ideal structures whose formal chacteristics and material elements have a definite internal relationship with one another and an actual, possible, or problematic relationship to external values. In mathematics, as in games and exercises generally, the material givens are postulated and the formal ones are rigid within each system. To change the rules is to exchange systems. Such is the not the case in art; although the language of the natural sciences is derived from mathematics, such is not the case in science either. In painting, poetry, sculpture, drama, fiction, music, and dance—and those branches of photography and gardening that become artistic—as in natural languages and not formal languages, a system of constructs is created that has definite but not fixed rules governing formal characteristics: rhythm, pattern, symmetry and asymmetry, rhyme, meter, balance, and shape. The conventions proposed are renegotiated constantly—not only in artistic "revolutions" like the introduction of atonal music—but in contexts as small as the balance among a few lines of poetry or measures of music. Precedent sets out a pattern and sets up an expectation and then surprises, frustrates, teases, or confirms that expectation. There would be no newness without the backdrop of pattern—no asymmetry without symmetry, no resolution without conflict, no harmony without tension, no negative space without positive mass or line, no revolution without tradition, and no tradition without change. The artist creates not merely by devising new material elements but by stretching and bending familiar rules and devices, constructing meaning not simply out of pattern but out of variance in pattern. Such variance is the sole possible sign of life or thought or theme.

Artists must create in order to communicate. They must abstract, and choose what to abstract and where—they cannot simply dish up what they see: the park, the landscape, flowers, walls and room. But art cannot be purely fictive either. It must have reference and a recipient as well as an author—and here again the artist must create, choosing the external values to which the fiction will be answerable, and the manner and degree: how much will be communicated, what values will be slighted or omitted, what will be degraded or made sacred and how will this be expressed? Chagall was once asked why he had placed a large blue cow in the sky over a house in one of his paintings. He replied that the work had seemed incomplete until just this figure was placed there. Chagall was responding to requirements of a context and structure that he himself had devised. He was showing deference to values drawn from the external world in accordance with criteria of selection that he himself had chosen.

Now scientists too create fictive constructs—the theories, hypotheses, models of entities, qualities, combinations of forces, with which they populate their theoretic universes. And scientific constructs, like those of art, must answer to external values. Science differs from art in that the external values include mandatorily a maximal set of external givens, the data construed as facts or factual implications of all viable (compossible) constructs. Unlike mathematicians, scientists cannot insulate their constructs from the acid bath of such universal exposure—except by heuristic retreat from science into mathematics itself, treating hypotheses as pure fictions whose interplay with fact is temporarily suspended. Unlike artists, scientists cannot choose the relative weightings to be assigned to facts. Hypotheses, unlike other fictions, must be earnest and foursquare with all that is taken as real. They must take seriously all that might potentially claim a place within fact. But the creative activity of the mind in choosing values is still present in science, crucially, at every stage:

1. *In detection of a problem.* Apprehending a paradox or anomaly is always recognition of a formal disparity—an asymmetry, breach of continuity. Even in direct contradictions among diverse theories, the problem is formal, and value choices must be made in assigning weights to each branch of inquiry and its evidence. The scientist, like the artist, must choose creatively among established and as yet unconceived

criteria of congruity and incongruity, restructuring the very rules by which the order of the world is reconstructed. The reason, in the scientist's case, is the earnestness of science. The scientist is engaging not in a game but with reality. This earnestness corresponds exactly to the earnestness or sincerity of art.

2. *In selecting problems for inquiry.* The scientist must determine which unresolved problems can or must be lived with and which will be treated as problematic practically. To question all would be paralytic. To question none, deadening. But, like the artist and unlike a machine that works within fixed rules, the working scientist must be ready constantly to revise working guidelines and even basic assumptions or there will be no progress of knowledge—no advance beyond the given.

3. *In framing hypotheses.* This is the area of scientific activity most neglected or distorted in rigidly empiricist accounts—assigned to chance or mystery, play, genius, or some other black box or ouija board. My thesis is that scientists frame hypotheses that go beyond the given in much the same way as other artists do, building from elements of experience, analogy, metaphor, model, suggestion, image, hope, fear, or dream—elements not wholly supplied by the data interpreted. The initial conditions, employed prior to testing, are wholly structural, invoking rather than appealing to formal principles—symmetry, balance, pattern, and the like—selected and elaborated on purely formal grounds. The analogy with art is perfect in this phase. Value judgements are made constantly about what premises or images to advance or restrain. And, as in art, the phase of reality testing can begin only when hypotheses are gelled and structured—concrete enough in implications—to afford them an identity and character that allows their interaction with external values. The difference with art, once again, is the elimination in the interactive phase of discretion vis a vis the factual world (or what is taken to be such) as a whole. But still discretion operates. Individual putative facts can and must be dismissed, temporarily or in favor of the hypotheses that best coordinate the totum of factual data. No one fact is sacrosanct, as a machine would make a datum, and the criteria of weighting again involve selection on the basis of formal values ranging from congruence or coherence to higher values such as elegance. In every case, these are in effect aesthetic values.

4. *In evaluating hypotheses.* It is notorious that an infinite set of non-self-contradictory hypotheses are capable of explaining any given set of data, if explanations are understood to be consistent with the data and capable of implying it. No machine could anticipate or even list all the hypotheses that could explain any factual datum, and no mechanistic process could begin to evaluate the set. I say no machine could *begin* because no unguided machine could generate its own rules for

determining where best to initiate a survey of an infinite field; and of course it could not traverse that field. I am prepared to argue that the infinite available hypotheses that might explain any given factual datum are not countably but uncountably many. For there are at least countably many hypotheses regarding the potential relevance of each move made or neglected in a single chess game. Further infinities of hypotheses remain regarding every other single event or combination of events that has occurred or might occur. The hypotheses that might be pertinent to the explanation of any given event thus remain uncountable—let alone unexaminable.

Scientists, we say, prescind from all such worries and focus on what is important. That is, they do not evaluate hypotheses mechanically: they make value judgements in choosing what hypotheses even to consider, let alone to test. And they do so on the basis of criteria from an openended set, a set that is open to the universe, flexibly responding even in its criteria of factuality to all that is presented or apprehended. Even with the hypotheses that must be considered seriously there are ungovernably many. And the material terms of validated hypotheses are not determinable a priori from the givens of prior theories. The Newtonian notions of mass, inertia, force, and gravity were not deducible from the data on which Kepler founded his laws of planetary motion. They were not deducible even from Kepler's laws, although in a sense they were singled out by those laws, as is easy to recognize with the help of hindsight. They were "determined" in the same sense as Chagall's blue cow—by rules of an aesthetic that does not allow itself to avert attention from anything held to be real. But they were not deducible. The data contained no mention of an ellipse. The figure became apprehensible only on Copernican assumptions. And the formula of an ellipse contains no reference to gravity or inertia as vectorial determinants of its shape. No machine could elicit such notions from this geometry unless they were supplied to it.

Theologically, the idea that the patterns of nature are not subject to a priori deduction from established principles has been expressed in terms of voluntarism: there are unpredictably many ways that God might have made the universe. There is no way of predicting the biochemical properties of vitamins or hormones a priori from a knowledge of the chemical properties of their elements. We can recognize relationships between higher and lower order properties and seek to account for them. But we cannot reduce one sort to the other—as in the ancient theories that attributed anger to a fiery temperament. At best we can apprehend in the elaborated, always partially self-defining complex, elements of explanation—material formal or informational, energetic, existential—grounds for the possibility of what has emerged.

The richness of natural possibility is the natural foundation for the necessity of empiricism in science: human knowledge of nature must be empirical in large part because nature itself is creative, not simply playing out fixed rules but elaborating themes and variations. We can appreciate the structural relations only as we apprehend them. We recognize and formulate a pattern, but we cannot formulate mechanically and a priori what it is to be a pattern. In saying that the scientist's work is necessarily empirical, we are resting on the more fundamental fact that the scientist's skills are necessarily prophetic: the scientist detects patterns emergent in a background of seeming disorder, discovering meaning in seeming noise. The rules by which such work is done can no more be laid down rigidly in advance than can the rules of poetry, music, painting, or sculpture. In dance, drama, or the other arts, we can recognize after the fact or in the act of creation a kind of necessity, which is no more than a sense of "rightness" derived from the recognition that things are in accord with contextual standards that (in part) the work itself defines. The same (and no more) is true about the necessity—or, better, rightness—of scientific explanations. Natural causes may necessitate in their own peculiar way. But, scientifically, when we work back from effects to causes, we shall never have more than hindsight. We project how things might have been done and then, with an assurance that recapitulates but cannot exceed the authority of the artistic creation, we grasp how they must have been done.

5. *In requiring creativity for scientific experiments.* Here, again, as in the related process of framing hypotheses, synthesis is involved, determining the contextual significances by which specific data would lend or diminish support for a given thesis. Since hypotheses are infinite and infinitely augmentable, there will never be a strictly conclusive crucial experiment—neither for refutation nor for verification. For the cases are symmetrical, as I have argued elsewhere. But there will be good reasons, nonetheless, for believing some theories well confirmed and others less so, and some whole types of theory too far-fetched to warrant inquiry. The most general modes of restricting hypotheses now in use in science might be described in terms of rationalism, naturalism, and empiricism. These coexist in a fairly stable but still fluid coalition. Their content and equilibrium are sometimes disturbed by dogmatic or excessive notions (e.g., no action at a distance, no wave without a medium, *natura non facit saltus, natura abhoruit vacuum,* experience is confined to atomic sensa, etc.). I suspect that because of such dogmas and excesses passing as flagships of science, the relations of the natural sciences with metaphysics, theology, the human sciences, and liberal arts have been historically unsteady, at times confined to the exchange of embassies and delegations and the attempt to set up mutually

recognized, safe borders. Each science, like the provinces of an empire, has its own internal rules under the overriding (but constantly reclarified) constitution. Such rules often have the strengths and weaknesses of other provincial structures, blending practicality and parochialism.

My thought this afternoon has been that just as human social progress can be impeded by a failure to understand that laws are human institutions, subject to change and reinterpretation and valuable only to the extent that they are sensitively understood, thoughtfully interpreted, and discerningly obeyed, so the state of science, its progress and commerce with other realms of creative effort, depends on recognition of the role of creativity in science, the non-mechanical, thoughtful aspects of the scientist's work, which can never be accomplished by weighing, measuring, numbering, and counting, no matter how much time scientists may spend in such activities. All really valuable scientific work, like all that is of value in art and poetry, is guided by ideas that emerge neither from chance nor from mere copying of external sources, human or divine, but from the constructive explorations of intelligence, which discerns values of structure and formal pattern in the givens of experience and brings them before the tribunal of experience. The activity is far too deliberate and orderly to be ascribed to chance, far too originative to be imputed to an external agency. In such work the human mind, I would argue, is more rightly seen not as a copyist or ventriloquist but as a partner or interpreter, in a finite way, of the creative work of the Divine.

Recently, much concern has been expressed about the pursuit of excellence in education. And much concern has been expressed about establishing the sciences and the arts—pragmatic as well as aesthetic—on a more creative footing. I am convinced that the two problems are related. All healthy babies, I believe, have as well-established and promising a capability for human creativity as any scientist, artist, or humanist ever requires. Just as all normal human infants utter every known phoneme in their pre-linguistic gurglings, and the instituted language of their society selects for contrast those phonetic values that are to be employed in a given linguistic system, so all infants explore, experiment, and tease; and all children question, evaluate, and reconstruct their environment. The silences and stillnesses we later observe in children and adults, then, must result from active stultification of such childish questioning, enforcing stillness out of fear of failure or success.

Only elaborate and sustained experiments could confirm the hypothesis I am proposing, but I would like to commend such an experiment to everyone here who is concerned with education—whether as a teacher or a scientist, humanist, parent, lawmaker, citizen, or student. In proposing such experiments, I have one outcome to suggest from the philosophic explorations we have shared in the past hour and over the past two days: Human creativity, like human liberty, is an equilibrium of freedom and responsibility. It is free in its exploratory and discovery phases and responsible to facts and numerous other values in its self-evaluative and validative phases. We liberate human creativity, then, not by imposing discipline and structure, which stifle creativity, nor by abandoning discipline and structure for a listless deference to undirected feelings and disconnected emotions. Rather, creativity requires an active integration of structure and discipline with questioning, fictive construction, probing, appetite, and passion. All really effective teachers know this already. By example and by articulate precept, they create a context of discourse that naturally engenders an appetite for learning and a passion for discovery. Their students will be the creative minds of the ensuing generation, and some of them will instill the same insightful passions and thoughtful appetites in others. This is not the time or place to propose sweeping panaceas in a single trenchant phrase. But one result that emerges most clearly from our analysis and from the deliberations of this conference as a whole is that the conditions that foster scientific creativity and those that foster artistic creativity are the same. I will go one step further, in terms of education: if we want to educate creative scientists, then we must teach our children to be poets; if we want to educate creative poets, we must teach our children to be scientists.

Accompanying Events

In the weeks prior to the Creativity and Science Conference itself, three events were sponsored, each designed to supplement the activities of the larger two-day meeting. These activities were to make the conference more accessible for anyone interested in the issues that were to be considered.

The first of these events was the Science in Pictures exhibit displayed at the Queen Emma Art Gallery March 1-24, 1985, and then at Windward Community College from March 30-April 15. This exhibit of winners from the *Science 83* annual photography contest displayed the interplay of science and creativity that the conference sought to explore. The pictures had scientific and technological subject matter, but each revealed the human being behind the camera, reminding us that science is a human activity. The photographs were aesthetically pleasing and technically impressive, and a number addressed their subject matter philosophically. A more detailed account of the exhibit will be found in the following pages.

The second event was a preconference workshop held at Honolulu Community College on March 5, 1985. The Principal Humanities Scholar, University of Hawaii professor Lenn Goodman, and the Project Director, Assistant Dean Diana DeLuca of Windward Community College, presented an overview of the conference program.

The third event took place on March 22, the evening before the conference began. The Hawaii Literary Arts Council cosponsored a poetry reading at the Waikiki Aquarium. Those in attendance enjoyed refreshments provided by the Hawaii Science Teachers Association and heard two poets, Anthony Quagliano and Joseph Stanton, read from their and others' work concerning poetic views of science. An edited version of their presentation is included here, although without the barks of the aquarium's seals that punctuated the actual event.

Science in Pictures

Diana M. DeLuca

Each year, the American Association for the Advancement of Science, through its publication (now *Science 86*), sponsors a photography contest. There are several categories, generally conforming to various scientific disciplines, each calling for black and white or color entries. The primary requirements for judging are that the subject matter must be scientific or technological, the photography impeccable, and the result artistic.

In comparison with other forms of human self-expression, photography is relatively new and has been the victim of a certain amount of controversy among more established artistic circles. It is still not uncommon to hear the argument that only certain (limited) branches of photography deserve to be called artistic. Usually excluded, as is the case with drawing and painting, are commercial products or illustrations of technical or scientific work. The argument founders on some magnificent exception, often Leonardo da Vinci or any one of a number of fine documentary photographers, but the prejudice lingers and not only in the minds of the artistic elite. I have heard architects, scientists, and engineers disclaim the artistic merit of what they do; in many cases, what they have produced is full of charm and vitality, but they too have subscribed to a very specific idea of "art." It is good, therefore, to have a contest that recognizes that photography deserves to be judged on artistic criteria.

In a contest such as this, which sends amateur photographers out into the world looking for the unusual and the beautiful, the results are inclined to be eclectic. This indeed was the case when the *Science 83* contest winners were displayed at the Queen Emma Gallery in Honolulu, March 1-28, 1985, in conjunction with the Creativity and Science conference. Prize winners ranged from studies of animal life, to geology, to x-rays. One was immediately struck by the fruitful partnership between the human eye and the camera. Together they revealed the natural world, outer space, and even the most vital organs that drive the human body.

There was no doubting the difficulty that each picture had created for the photographer. One winner had set his camera to record the sun's position at the same time each day. The result was a figure eight of suns over a year. The picture on display, we were told, was his second attempt, his first having been spoiled well into the project by a power outage. Another photographer must have hunched over his close-up lens adjusting endlessly to record the honeycombed eye of a fly. Another dived into South Pacific waters to play voyeur to a pair of mating sea slugs. Still another x-rayed a human heart, revealing the tissued, filmy layers of the muscle structure, more like a hologram than a photograph. These were the intrepid voyagers of the contest.

Others were to find beauty in more familiar places. They were well represented by the little triumphs, the ordinary made special: the tractor suddenly dramatic in the shadows of the afternoon sun, the sharp-edged silver prow of an unfinished battleship, a cloud formation hovering like a stalactite, the tension and explosion of a soap bubble, and the crenulated crevices of erosion-worn cliffs. These were the patient observers. How long did the camera wait for the brightly green tree frog to pose on the grass blade? How long did it take to catch the two rattlesnakes writhing in competition in the prairie dust?

One cannot help wondering if these photographs would have been taken whether there was a contest or not. One hopes so, and there is evidence to suggest a contagious delight behind their creation. There is humor in a number of them—photographers can laugh after all. A row of porcine tails, their owners' snouts no doubt happily buried in slop, are curly-coiled in a row at a state fair—enough to give one pause at the breakfast table. The sympathetic historian of an anemone colony in Puget Sound tells us of their one danger: nearby fat starfish who occasionally invade and stampede the panicked anemones.

The "Science in Pictures" exhibit was an ideal accompanying event to a conference on creativity that sought to find what the sciences and the humanities have in common. The pictures demonstrated many of the features that the presentors linked with creativity: the ability to grasp a moment of insight, the willingness to risk, and a joy and playfulness in exploring the world. No doubt, the techniques that produced the prints can be analyzed and the steps rationalized into some kind of pattern, but only a creative spark could have given these photographs the life they contain. A prepared mind was needed to recognize the moment that the print will now hold indefinitely. In many ways this exhibit is a record of us as a species: it shows us reaching beyond the limitations of vision and proves us a beauty-appreciating animal.

Poets on Science

Anthony J. Quagliano and Joseph P. Stanton

On Mauna Kea   fire mountain
    burst in fury from the sea
the sky, as everywhere, is Greek
    below the frost line
feral sheep scour the lava rock
    for pili grass

    further
on the high slope
    folkloric astronomers
record the semiotic night
    through a light dust of tropical snow

—Tony Quagliano

Poetry and science are enterprises concerned with the discovery and acquisition of knowledge about the world and ourselves in the world. Consider Wordsworth's conciliatory definition of poetry: "The breath and finer spirit of all knowledge; the impassioned expression which is in the countenance of all science."

Why then, if poetry and science have such common purpose, has there been a history of mistrust? The trouble lies partly in the poet's perceptions about the methods and techniques of science, that is, the poet's apprehensions about *technology*.

In an interview for *Rolling Stone*, Norman Mailer articulates these apprehensions. Mailer speaks of the war between God and Satan and allows that technology may be the handmaiden of either—of Satan perhaps to dull us and starve us spiritually so as to take control of our weakened state; or of God, to test us and strengthen and enrich our spiritual lives by daily resistance to the easy comforts that technology offers us.

In either of these Manichean scenarios it is clear that Mailer, along with some other recent analysts, takes technology to be the villain in human affairs. Jacques Ellul's *The Technological Society* most exhaustively promulgates this positon: technology is inferior to science, at best applied rather than pure science. Mailer makes a more complex distinction however:

> Q: Technology may be the opposite of science, then?
>
> M: Well, I think there's much reason to believe that it is. Science, for most of its history, was essentially a positive endeavor. Every metaphor, if you stop to think about it, is an equation. If you say "The sparrow is on the wing," that's a scientific remark, it's a way of saying that the sparrow exists in two manifestations at once, body and flight, just as light consists of waves and particles. The sparrow is on the wing. As you start to bear down on the language, you begin to feel the very vibrancy of the wing. You can fix on that point endlessly because it's a metaphor, an equation, a moment of balance. Originally, science had that quality, that its fundamental recognitions were, dare I say it?—poetic.
>
> Q: It was an art at that point?
>
> M: Absolutely an art. Technology is finally, I would suggest, a tradition, and a dull one. A statistical tradition. (54)

In equating pure science and art, in this case literary art, and opposing both to technology, Mailer is saying that technology is not just an applied science, or practical science, or mere engineering, but rather that technology is the natural enemy and potential murderer of science as well as of art. Technology represents all that can be routinized, made standard and dull and sterile about the scientific enterprise or any other human activity.

In *Literature and Technology*, Wylie Sypher exceeds even Mailer in showing how technology can destroy art. The values of technology—parsimony, efficiency, the one best way of addressing a task—have a leveling and standardizing effect no matter in what realm they are employed. "A law of parsimony," Sypher says, "worked in aestheticism as it did in science." For Sypher, technology is indeed the villain, and he traces its origin to the last century (xvii).

The aesthetes of the nineteenth and twentieth centuries did indeed attempt to engineer works of art by determining formal systems of criticism and evaluation with which "genuine" works were to conform. It was against this that Robert Bly spoke out, urging poets to learn from the surrealist poets of Latin America and Europe rather than the academics of the universities. He called on them to avoid producing more poetry "made sterile by a lunatic emphasis on technique."

But there is no doubt that poetry can survive during a scientific age and there are many who disagree with Mailer and Sypher. British poet and critic Donald Davie is one:

> Historians of ideas are often nowadays solicitous for the poets; and the latter, as often as not, are churlish in their acknowledgements.

> The truth seems to be that the poet is sturdier, and his attitudes less calculable than the historians suppose. There is a notion abroad that what is "organic" is a good thing for poetry; and it follows that what is mechanical isn't. The poet, however, takes his metaphors where he finds them, and may choose to extol the Brooklyn Bridge, no less than the meanest flower that blows. As Hart Crane declared, himself the laureate of the Brooklyn Bridge, "The familiar contention that science is inimical to poetry is no more tenable than the kindred notion that theology has been proverbially hostile—with the *Commedia* of Dante to prove the contrary." (5)

With the Brooklyn Bridge, a triumph of applied science, the subject of one of America's finest poems, then the disparagements made by Mailer, Sypher, C. P. Snow and others are incomplete. Good poetry—good art in general—should come from anywhere, certainly including technology.

Czechoslovakian poet and scientist (immunologist) Miroslav Holub is one who would certainly agree: "There is no deep difference between the scientific mind and the artistic mind: both include the maximal creativity with the maximal freedom. Science is both theoretic and experimental. Art is only experimental" (50). The key word here is obviously *experimental*. In the arts, we sometimes use this term as a label for works that depart strikingly from the norm. Holub reminds us that every poetic work is an experiment. If the poem "works," a hypothesis has been proved. Determining the success of his experiments is perhaps harder for the poet than the scientist.

In the "experiment" that follows, the speaker attempts to use his experience as an outside observer of science. Joseph Stanton's "Solving the Universe" is a whimsical work that both complains about and celebrates science:

Solving the Universe

Science has its tools
for unmasking
all that is
or could be.
For sensing and counting
for breaking down the world
into knowledge:
marks on a page or screen
that click, click, click
as they are printed
out.

The instruments of science
tell us
amazing truths:
that mass does not like to change,
that things keep their distances
from finger tip to funny bone,
that nature's got rhythm,
that earth spins and bulges,
that gravity swings and air springs,
that vacuums void and mountains float,
that stars pulse
and white light separates
into glory.

The tools of science
are a lovely danger.
They are in our hands,
and we in theirs.

The speaker of this poem is an outsider, a heckler in the audience witnessing the drama of science. When Mirsolav Holub writes of science, however, he is both on the stage and in the audience. This dual perspective is evident in a poem such as "In the Microscope," where science helps him to understand the world at the same time as the world helps him to understand science. Within the lens of his microscope, Holub sees a strange and yet familiar landscape where cells "lay down their lives/ for a song" (25). Writing over twenty years before Lewis Thomas was to reflect on the lives of a cell, Holub dramatizes the analogy between the human and the microscopic worlds.

Another poet who lives in the worlds of art and science is Dannie Abse, a London physician. In his "Letter to Alex Comfort," his most widely admired scientific lyric, he describes three kinds of science. The first is what he calls "German thoroughness" as practised by Nobel Prize-winning bacteriologists, Paul Erlich and Robert Koch.

Practitioners of the second kind of science, the kind that the speaker prefers, are called "unkempt voyagers" and "butterflies drunk with suns." What the speaker seems to like about the stories that surround these almost mythical figures is that they managed to transform the world through bizarre and miraculous inspirations. These discoveries are at the same time both silly and immensely important. His first example is Archimedes, who ran out naked from his bath shouting "I found it!" without realizing that everyone on the street would merely gawk at his exposed genitals and laugh. His second example is Newton, who altered the history of science simply by observing--"with true gravity"—the fall of an apple.

The speaker then talks about his own and his friends' hunger for new miraculous discoveries and their fear that none will come their way. These fears are compounded by their concern over the possibility that science is too often of a third type that is merely clever and cruel and bent toward destructive, even warlike, ends.

The best-known American poet-scientist is probably Loren Eiseley. It might be argued that his lyrical gifts achieve more complete expression in his essays than in his poems, but his best poems, like his best essays, do manage to reveal his vision of a universe whose mystery is only amplified by all that science tells us. In "The Shore Hunters," for instance, he vividly describes an archeologically important site and then declares that "the archeologist / is an anomaly here." He suggests that the archeologist cannot lead us to a complete understanding of the depths he has unearthed: "The bones of the elephant, / the sandals in the cave . . . / speak to no one in particular."

Repeatedly in his literary writing, Eiseley pushes against the limits of what he can investigate as a professional archeologist. In his work, the essayist-poet and scientist are sometimes at odds, but often the scientist willingly joins the quest of the essayist-poet. At such moments, Eiseley is most impressive. The following poem by Joseph Stanton attempts to characterize the nature of Eiseley's scientific and humanist quest. Most of the poem's images refer directly or indirectly to well-known Eiseley essays:

Librarian of the Night
for Loren Eiseley

The light of day is a habit
the mind puts on
and tries to believe in,
reading volumes and velocities
of every bird in flight,
trajectories of all the flowers
that have changed the world.
But always, always
we are groping for a way
into the darkness:
a hole in the hedge
that leads to impossible truths,
where reasonable madness schemes
in the attic of the heart,

known as the head,
making unimaginable lightnings
crackle blue-white
across the middle of the night.

Eiseley says
that the searches of science
must be sad, autumnal magic;
that sedate, white stepping stones
must become pathways wild
and haunted by the moon.
Seeking, he says, the secrets there,
we must become all eye,
a pharos light, a beacon,
searching
by turn and turn about
in the hollow of the skull,
where the world takes place
and does not take place,
knowing that the dark
is teeming with stars
that live by burning
out.

But even when the scientists and poets do become "all eye," there always remain questions about what the eye is actually seeing, questions concerning what constitutes knowledge. It is, therefore, appropriate that we end with a poem by Tony Quagliano that entertains and is entertained by Heisenberg's uncertainty principle:

Oldenburg, Heisenberg and Oscar "Shotgun" Albarado

What counts in what we
know about a thing
is how
we got to know it,
what the instruments
of measure
were.

Sluggish distance, geographically
is miles
while weightless computations

charting stars, require
we call distance
years.

Time of day is told by
burning rope, or falling sand
shadows on a stone
or wheels fitted close
and set in motion.

Today in Pasadena
Oldenburg's exhibit
showed me this again,
that form alone
describes
an object,
knowing objects
by a name, or use
is indeterminate.
"The Trowel is a hard version
of the swans
that live in the lagoons . . .
and relates also
to the Good Humor Bar
the Door Handle
and is an exotic form
of the Ray Gun."
"The Geometric Mouse
contains a human face."

"banana=fan
typewriter eraser=tornado
ice cream cone=punching bag
fire plug=ionic column
ice bag=fried egg"

Tonight I stopped off
in a bar on Pico
where the tv screen
showed rated welter
Shotgun Albarado
pounding out an
easy win

over some kid up from Hermosillo.
"The fights," the barkeep told me
"you can always tell
it's Thursday."

Is it possible that poetic work—by its example as well as by what it specifically states—has something to say of relevance to scientific work? Many of the poets who have written on scientific themes show evidence that they believe the reverse is wonderfully true: they have tried to learn habits of thought and kinds of form from science. But do many scientists return this interest? Alfred Alvarez, poet and literary critic, makes an interesting comment concerning the ways that he has observed scientists to relate to poetry:

> The gloomy general rule seems to be that, even with the best will in the world, the split between the two cultures is radical, if only because the scientists won't take the discipline of the arts seriously. So they go to poetry simply as *relief* from the intellectual stringency and sophistication of their professions. (9)

Whether or not science pays any attention to the poets' experiments, poets must continue to pay attention to science and must continue to try to transform it into poetry. Science, as Dannie Abse reminds us in his "Letter to Alex Comfort," often tries to make miracles, and singing about the making and unmaking of miracles has always been the poet's stock and trade.

List of Works Cited

Alvarez, Alfred. "Introduction to the Poetry of Miroslav Holub," in *Miroslav Holub: Selected Poems*. Baltimore: Penguin, 1967.

Abse, Dannie. *Collected Poems, 1948–1976*. Pittsburgh: University of Pittsburgh Press, 1977.

Davie, Donald. *The Language of Science and the Language of Literature, 1700–1740*. London: Sheed and Ward, 1963.

Eiseley, Loren. *Another Kind of Autumn*. New York: Scribner's, 1977.

Ellul, Jacques. *The Technological Society*. New York: Knopf, 1964.

Holub, Miroslav. *Miroslav Holub: Selected Poems*. Trans. Ian Milner and George Theiner. Baltimore: Penguin, 1967.

———. "Poetry and Science," in *A Field Guide to Contemporary Poetry and Poetics*. Ed. Stuart Friebert and David Young. New York: Longman, 1980.

Mailer, Norman. Interview with Richard Stratton in *Rolling Stone*, 16 January,1975, 54.
Sypher, Wylie. *Literature and Technology*. New York: Random House, 1968.

Biographies

Sharon Bailin is an instructor at the Faculty of Education, University of Toronto, and a Visiting Scholar at the Ontario Institute for Studies in Education. Her research involves a philosophical investigation of creativity, aesthetics, and philosophy of science.

Gillian Beer is Vice-Mistress of Girton College, Cambridge, and a University Lecturer in English. Her book *Darwin's Plots* (London 1983) won the Crawshay Prize of the British Academy in 1984. She is at present working on the relations between popular physics and literature.

Alfred Burger is Professor Emeritus in the Department of Chemistry of the University of Virginia. He has written nine books in the area of medicinal chemistry and founded and edited the *Journal of Medicinal Chemistry*. He holds an honorary degree from the Philadelphia College of Pharmacy and Science, and has received the Pasteur Medal (Paris 1953), the Smissman Award from the American Chemical Society (1977), and many other awards.

Milič Čapek is Emeritus Professor in Philosophy, Boston University. He is the author of *The Philosophical Impact of Contemporary Physics* (1961), *Bergson and Modern Physics* (1971), *The Concepts of Space and Time: Their Structure and Their Development* (1976), and *T. G. Masaryk in Perspective* (1981), as well as other books and numerous articles.

Christopher Chiaverina received his B.S. and M.S.Ed. degrees in physics from Northern Illinois University. He has been teaching physics at Barrington High School, Illinois, for the last fifteen years.

George Curtis is Technical Coordinator for the Hawaii Natural Energy Institute and Tsunami Research Specialist for the Joint Institute for Marine and Atmospheric Research at the University of Hawaii. He has thirty years of experience in engineering, science, industrial research, and education. He has published widely in these fields.

Lindley Darden received her Ph.D. from the Committee on the Conceptual Foundations of the University of Chicago in 1974. She is currently Associate Professor of Philosophy and History, and Chairperson of the Committee on the History and Philosophy of Science at the University of Maryland in College Park. Her research interests are in theory construction in science.

Robert de Loach is Chairman of the Social Science Department at Windward Community College, Kaneohe, Hawaii. He holds a B.S. degree in mathematics and master's degrees in social science and anthropology. He has performed field research in Hawaii and the Pacific Islands, and he has worked closely with the Office of Economic Opportunity and the Model Cities program.

Diana DeLuca is Assistant Dean of Instruction at Windward Community College and President of the Hawaii Council of Teachers of English. She holds a Ph.D. in English from the University of Washington. Her publications include *Pacific Marine Life* and articles on medieval and Renaissance literature.

Werner Diederich studied mathematics, physics, and philosophy at the Universities of Hamburg, Göttingen, and Tubingen. He is currently lecturer at the University of Bielefeld, West Germany. His publications include *Konventionalitat in der Physic* (1974) and *Strukturalishische Rekonstruktionem* (1981).

Margret Dreikausen is a professional artist who lives and works in New York City. She studied art in Germany and Switzerland as well as in the United States, and she has displayed her work in numerous art exhibits at international galleries. She is the author of *Aerial Perception, the Earth as Seen From Aircraft and Spacecraft and Its Influence on Contemporary Art* (1985).

Leon Edel is Emeritus Professor in English at the University of Hawaii. He is the author of numerous works on Henry James, including the biography for which he won the Pulitzer Prize. Other works include *Bloomsbury: House of Lions* and *Stuff of Sleep and Dreams.* He is also the editor of the Edmund Wilson and Henry James letters.

Lenn Goodman is Professor of Philosophy at the University of Hawaii. He has published extensively in the philosophy of science and in Near Eastern philosophy.

Ronald Gordon is Assistant Professor of Speech Communication at the University of Hawaii-Hilo. He is the co-author of *Communicating in the West* and has published in *Communication Quarterly, Journal of Communication Studies, Communication, Psychological Reports*, and *Small Group Behavior*.

George Greenstein is Professor of Astronomy at Amherst College. He majored in physics at Stanford University and attended graduate school at Yale. He has received postdoctoral scholarships at Yeshiva and Princeton Universities. He is the author of *Frozen Star*, a non-technical account of pulsars and black holes and of numerous articles on relativistic astrophysics.

James Huchingson is Associate Professor of Philosophy and Religious Studies at Florida International University in Miami. He attended Georgia Institute of Technology and worked for the Boeing Company at Cape Canaveral and NASA headquarters in Washington D.C. His graduate studies include the history of science and technology. He has a doctorate in philosophical theology from Emory University.

Mark Johnson teaches in the Department of Philosophy at Southern Illinois University at Carbondale. His research areas include cognitive science and the philosophy of language. He is the co-author of *Metaphors We Live By*.

Elaine Kleiner holds M.A. and Ph.D. degrees from the University of Chicago. Since 1969 she has been Professor of English at Indiana State University. She is currently working on a series of reviews of the "new science literature."

Alfred Kracher studied chemistry at the University of Vienna. He worked as a geochemist in the Department of Mineral Sciences of the Museum of Natural History in Vienna before becoming a postdoctoral fellow at the Institute of Meteoritics at the University of New Mexico. He is currently Research Associate in the Department of Earth Sciences at Iowa State University. His research interests include meteoritics, cosmochemistry, and microanalytical techniques in rock and mineral analysis.

Tyrone Lai teaches philosophy at Memorial University, Newfoundland. He is working on a new theory in epistemology that has important implications for the philosophy of science and ethics.

Glenn Leto received his B.S. and M.S. degrees in zoology from Northern Illinois University. He has been teaching biology at Barrington High School, Illinois, for the last fifteen years. Additionally, he is a major contributor to *Biology* (Harcourt, Brace, Jovanovich, 1986).

Peter Manicas is Professor of Philosophy at Queens College, the City University of New York. He has published books and articles in logic and scientific method, the philosophy of psychology, and social and political philosophy. He is currently completing a critical history of the social sciences.

Claudia Melear has been a high-school biology teacher for seven years. She has taught both regular classes and classes for gifted students. She is currently working on a Ph.D. in science education at Ohio State University.

Arthur I. Miller is University Professor of Philosophy and History at the University of Lowell and Associate of the Physics Department at Harvard University.

Harold Morowitz is Professor of Molecular Biophysics and Master of Pierson College at Yale University. He has written extensively on the interface of the sciences and the humanities. His most recent book is *Mayonnaise and the Origin of Life*.

Gonzalo Munévar holds a Ph.D. in philosophy from U.C. Berkeley. He is Professor of Philosophy at the University of Nebraska at Omaha, and has been Visiting Associate Professor of Philosophy at Stanford University as well as Faculty Fellow at the Stanford Humanities Center. His most recent book is *Radical Knowledge: An Inquiry into the Nature and Limits of Science*.

Christopher Nevison is a member of the Computer Science Department at Colgate University. He holds bachelor's degrees from Dartmouth and Oxford Universities and a Ph.D. in mathematics from Stanford University. In addition to teaching in his specialty, he has been active in Colgate's General Education program.

Daniel Noel is Professor of Alternative Education in the Adult Degree Program at Vermont College of Norwich University, Montpelier, Vermont. He edited *Echoes of the Wordless "Word"* (introduction by Joseph Campbell) and *Seeing Casteneda*, and he has written numerous essays and reviews in religious studies, literature, and depth psychology.

His most recent work, due out in the winter of 1985–86, is *Approaching Earth: A Search for the Mythic Significance of the Space Age.*

Loraine Obler is Associate Professor in the Department of Speech and Hearing Sciences at the CUNY Graduate Center where she works on the neurolinguistics of bilingualism and dementia. She received her Ph.D. from the University of Michigan and has worked at the Aranne Laboratory for Human Neuropsychology of the Hadassah Hospital of the Hebrew University and at the Aphasia Research Center of the Boston University School of Medicine. In addition to her forthcoming work, *The Neuropsychology of Talent and Special Abilities*, she has published *The Bilingual Brain: Neurolinguistic and Neuropsychological Aspects of Bilingualsim* and *Exceptional Language and Linguistics.*

Wayne Owens teaches philosophy and humanities at the University of Texas at San Antonio. He holds a Ph.D. in philosophy from De Paul University.

David Paxman is Associate Professor of English at Brigham Young University-Hawaii Campus. He received his Ph.D. from the University of Chicago.

Richard Penaskovic is professor and chair of the Department of Religion at Auburn University, Alabama. He received his Ph.D. in theology from the University of Munich, and has published one book and over thirty articles in international journals.

H. R. Post is Professor of Philosophy at Chelsea College, University of London. He studied classics at the Collegium Fridericianum in Koenigsberg, chemistry at Trinity College, Cambridge, where he was Millard Scholar, and physics at Chicago University.

Anthony Quagliano is a poet and writer. His poems have appeared in *Rolling Stone* and *New Letters*, among other publications. His recent prose includes an article, “Signs and Symbols,” in the *Encylcopedia of Psychology* (1984).

M. R. Raju is a Fellow at the Los Alamos National Laboratory. He was born and educated in India and has been living in the United States since 1961. His research is in the area of radiation biology.

Daniel Rothbart is Associate Professor of Philosophy at George Mason University in Virginia. He has written on the nature and function of metaphor within scientific reasoning. He has published in *Dialectica, Philosophy of Science*, and *Methodology and Science*.

Joseph Stanton has published in *Blue Unicorn* and*Concerning Poetry*, among other publications. A recent essay on poetry and the visual arts appears in *Windless Orchard*. His latest book is *British and American Literature*, a textbook for high school students.

Pat Takahashi is Director of the Hawaii Natural Energy Institute and Professor of Engineering at the University of Hawaii. He has previously worked in the U.S. Senate (as an aide to Senator Sparky Matsunaga), Lawrence Livermore Laboratory (laser fusion), NASA Ames Research Center (search for extraterrestrial intelligence), and for the Hawaiian sugar industry. His research and teaching interests include energy, laser applications, environmental engineering, and technology and society.

Paul Tang is Assistant Professor of Philosophy at California State University, Long Beach. His current research includes problems in the history and philosophy of biology, scientific development, philosophy of psychology, artifical intelligence, aesthetics, and Asian philosophy. He is also a musician.

Nancy Tuana teaches in the school of Arts and Humanities at the University of Texas at Dallas. Her research areas include the philosophy and history of science and feminist theory. She has published articles in the *Philosophy of Science, Philosophical Studies, Hypatia, A Journal of Feminist Philosophy*, and *Soundings*.

George Wald is Professor Emeritus at Harvard University. He earned his Ph.D. in biology at Columbia University and his work on vision won him the Nobel Prize in Biochemistry in 1967. In recent years, he has been interested in economics and human rights, devoting much of his time to lecturing.

Frank Watanabe has thirty-four years of experience in working with university YMCA students.

Acknowledgments

The Hawaii Council of Teachers of English gratefully acknowledges the support of the following funding agencies

Atherton Family Trust
Exxon Corporation
Faculty of Arts and Humanities, UH-M
Faculty of Language, Linguistics, and Literature, UH-M
Faculty of Natural Sciences, UH-M
Foodland Supermarkets
Gannett Pacific Corporation
Hawaii Committee for the Humanities
Hawaiian Electric Company
Honolulu Advertiser
*Sigma Xi:*National Science Honor Society
and *Sigma Xi:* Hawaii Chapter
University of Hawaii Foundation

Cosponsoring agencies that have worked with HCTE to develop this conference include

American Association for Advancement of Science
American Association of Women in Community
and Junior Colleges
College of Tropical Agriculture and Human Resources,
Publications and Information Office
Consortium of Science Humanists
Department of Philosophy, UH-M
Hawaii Association for Supervision
and Curriculum Development
Hawaii Literary Arts Council
Hawaii Science Teachers Association
Honolulu Community College
University of Hawaii Philosophy Students Association
Waikiki Aquarium
Windward Community College

The following businesses and organizations donated goods and services to the conference

Bank of Hawaii
Coca Cola of Hawaii
First Interstate Bank
GECC Financial Corporation
Hawaii Newspaper Agency
Hawaii Visitors Bureau
Hawaiian Telephone Company
Hertz Rent-a-Car Agency
Pentagram Corporation (Burger King)
Postal Instant Printers
7-Eleven Stores
Straub Clinic and Hospital
University of Hawaii Bookstore
Windward Community College Bookstore
Windward Community College Associated Students
and WCC Konohiki Student Council

Special thanks are due to the following people whose participation made the conference possible

University of Hawaii President, Albert Simone; Chancellor of the University of Hawaii Community Colleges, Joyce Tsunoda; Lillian Cunningham, Provost Peter Dyer, Roy Fujimoto, Phillip Hagstrom, Snowden Hodges, Dean Hiroshi Kato, Suzanne Kita, Kim Kiyono, Jacquie Maly, Clayton Masuda, Roy Muramoto, Otome Myers, Margo Stahl, William and Opal Terbeek, Irene Tokuda, Emi Troeger, Richard Walenta, and Libby Young of Windward Community College; Alison Kay, Renee Kojima, Flora Sakamoto, Dean Robert Pecsock, Dean Richard Seymour, and Dean Rex Wade, of the University of Hawaii-Manoa; Monte Hickok, Provost Peter Kessinger, and Ronald Pine of Honolulu Community College; Elizabeth McGonigal and Judy Thomas of Mid-Pacific Institute; Marilyn Dunlap and Madeleine Goodman of *Sigma Xi*; Francis Pottenger and Pearl Takeuchi of Hawaii Science Teachers Association; Marjorie Sinclair Edel and Lorna Evans of the Hawaii Literary Arts Council; Kathy Damon of the American Association of Women in Community and Junior Colleges; Mary M. Logasa of the Hawaii Association for Supervision and Curriculum Development; Masa Taira of Queen's Medical Center Auxiliary; Fritz Rehbock of the Consortium of Science Humanists; Bob Buss and Annette Lew of the Hawaii Committee for the Humanities; and Don Mair of the University of Hawaii Foundation.

Also the following officers and board members of the Hawaii Council of Teachers of English: Lynn Henrichsen, Kay Porter, James Wilson, Frances Shimotsu, Sandra Wong, Cathy Kawano-Ching, and Larry McGonigal.

Author Index

(Italics indicate biographic information)

Bailin, Sharon 175, *297*
Beer, Gillian 255, *297*
Burger, Alfred 211, *297*

Čapek, Milič 17, *297*
Chiaverina, Christopher 137, *297*
Curtis, George D. 247,*297*

Darden, Linley 25, *298*
de Loach, Robert E. 247, *298*
DeLuca, Diana M. v, 285, *298*
Diederich, Werner 31, *298*
Dreikausen, Margret 181, *298*

Edel, Leon 111, *298*

Goodman, Lenn E. ix, 269, *298*
Gordon, Ronald D. 53, *299*
Greenstein, George S. 217, *299*

Huchingson, James E. 187, *299*

Johnson, Mark L. 225, *299*

Kleiner, Elaine L. 62, *299*
Kracher, Alfred 81, *299*

Lai, Tyrone 157, *299*
Leto, Glenn 137, *300*

Manicas, Peter T. 142, *300*
Melear, Claudia T. 242, *300*
Miller, Arthur I. 124, *300*
Morowitz, Harold J. 203, *300*
Munévar, Gonzalo 89, *300*

Nevison, Christopher 150, *300*
Noel, Daniel C. 194, *300*

Obler, Loraine K. 68, *301*
Owens, Wayne D. 73, *301*

Paxman, David 97, *301*
Penaskovic, Richard J. 102, *301*
Post, H. R. 43, *301*

Quagliano, Anthony J. 287, *301*

Raju, M. R. 236, *301*
Rothbart, Daniel 163, *301*

Simone, Albert. J. vii
Stanton, Joseph P. 287, *302*

Takahashi, Patrick K. 247, *302*
Tang, Paul C. L., 167, *302*
Tuana, Nancy 225, *302*

Wald, George 1, *302*
Watanabe, Frank 247, *302*